OCTOBER 1955

THE WELDING JOURNAL

1955 AWS NATIONAL FALL MEETING

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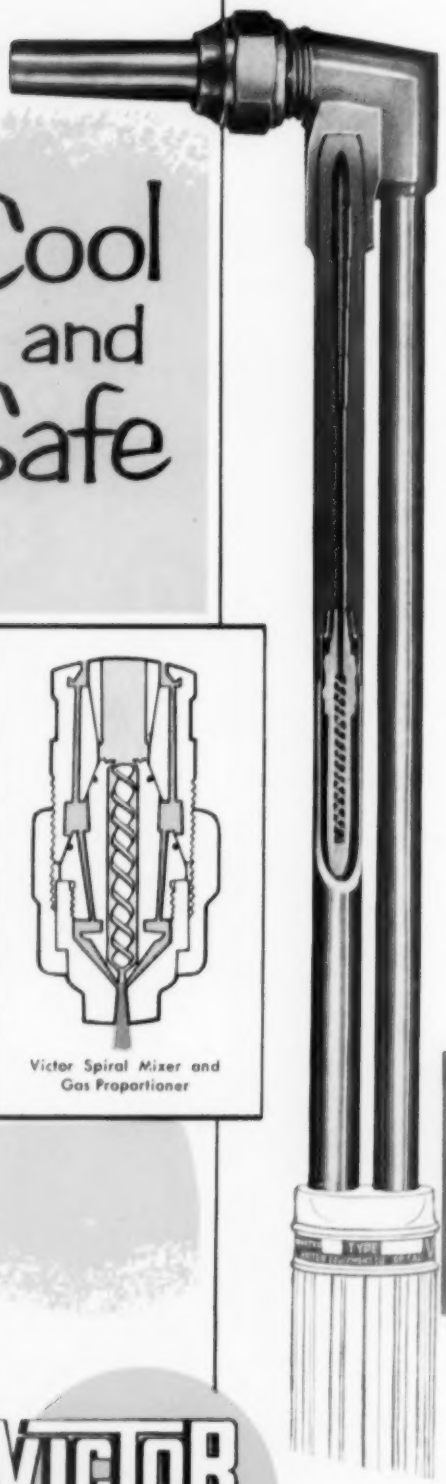

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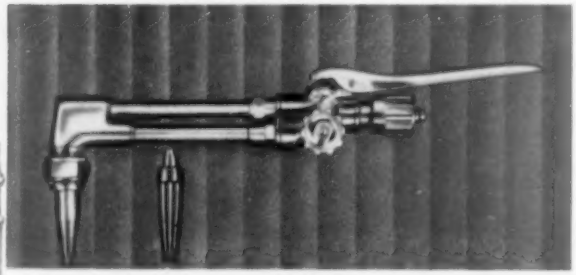

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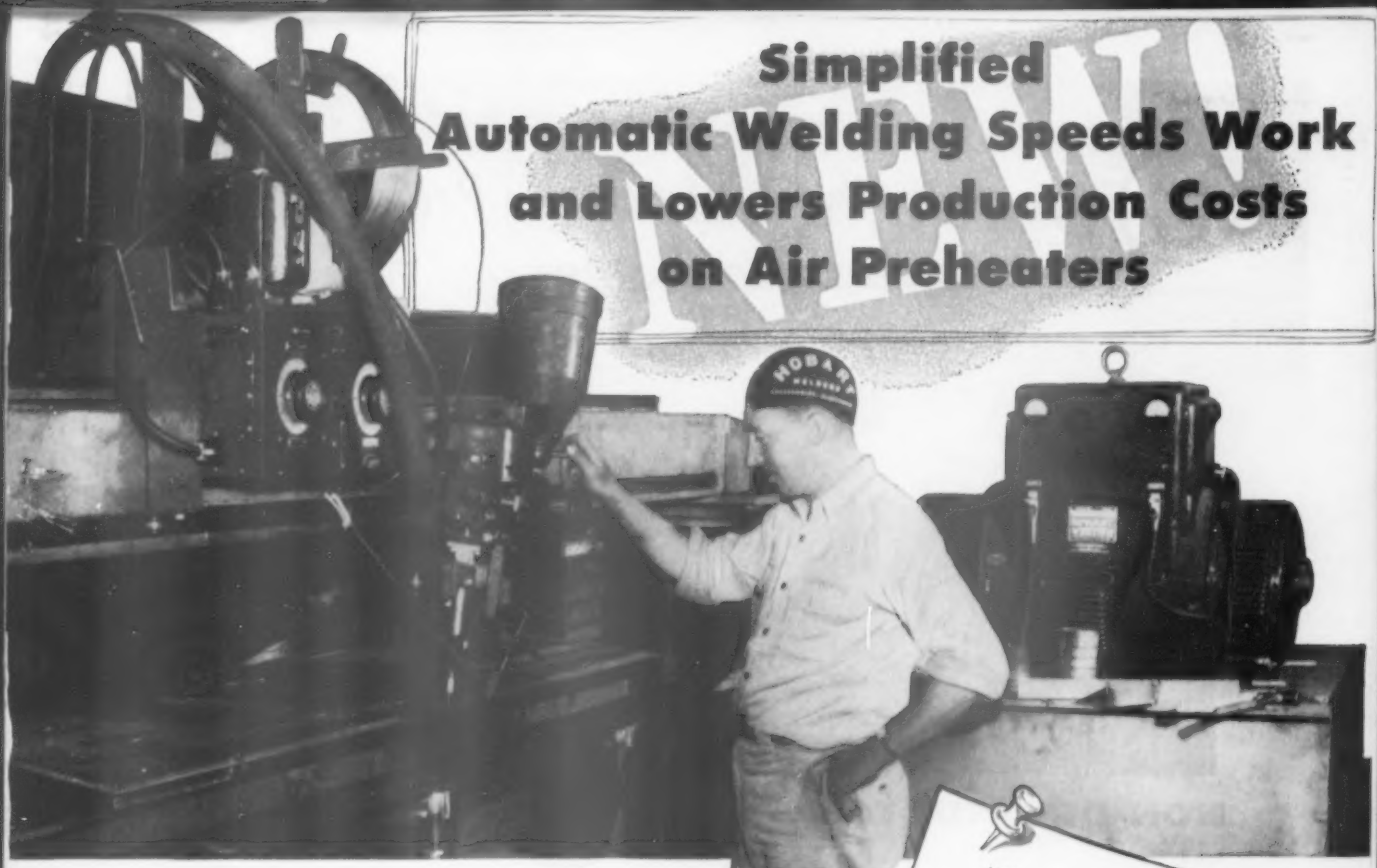

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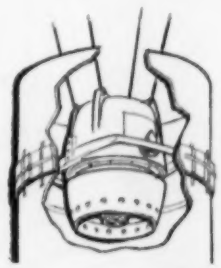

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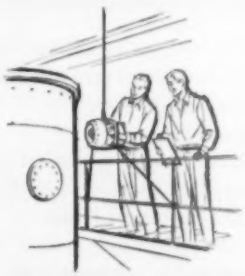

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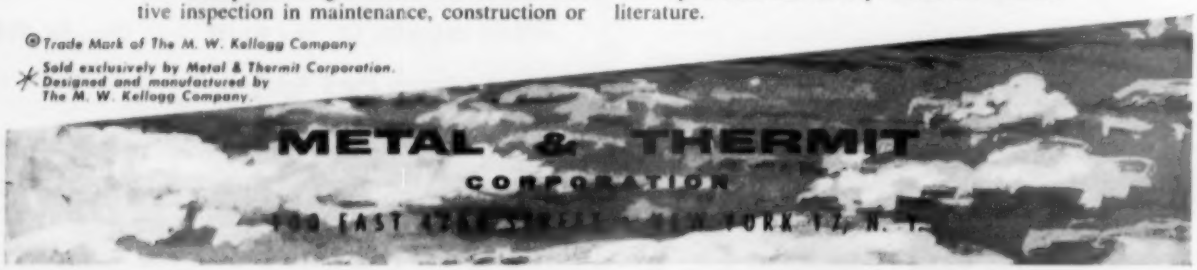

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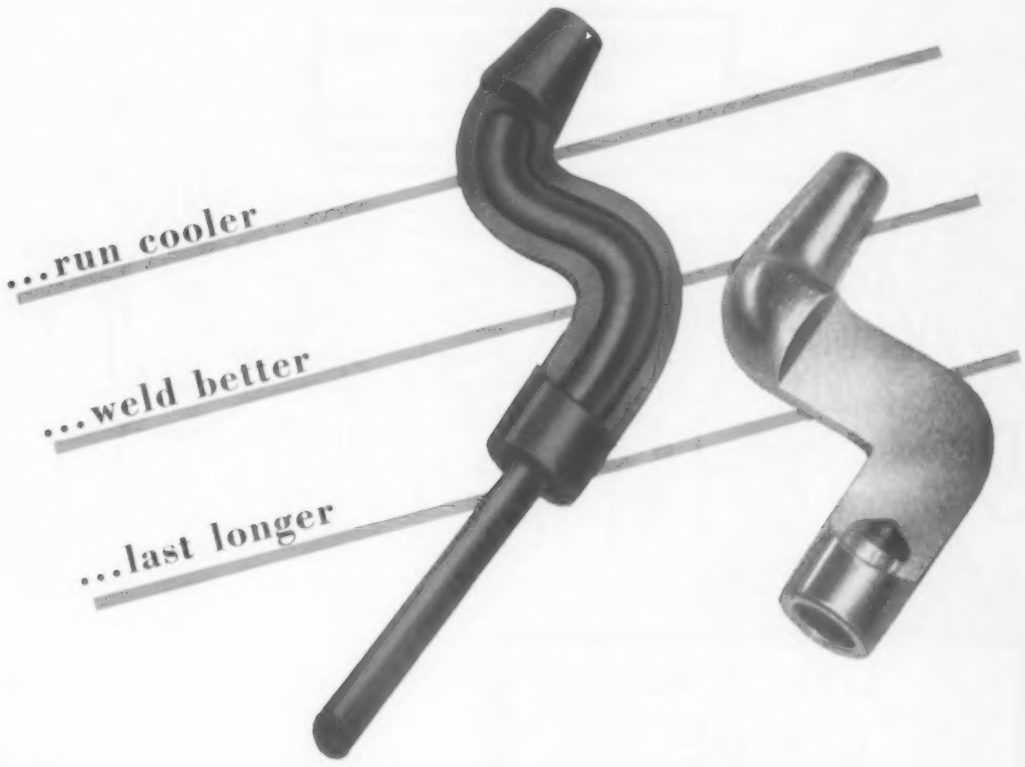

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THE WELDING JOURNAL

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WELDING AND ITS CONTRIBUTION

The $64,000 question today is: "Where would we be were it not for welding?" It is difficult to find any other single factor that has contributed so much to our industrial economy as we know it today. The greatest industrial expansion in the history of our country has occurred in the past 25 years. This was just about the time that welding came into prominence as a fabricating tool.

It was the welded ship that "saved the day" during World War II. The welded pipe line broke the bottle neck in transporting oil and gasoline to the places where it was needed the most.

Welding in the aircraft industry enabled us to strike fast and effectively. The welded tank saved thousands of Americans lives.

It has been said that welding has made it possible for automobiles to be sold for one-fourth to one-third less than would be the case in the wood frame body.

The extreme high-pressure power plant boilers producing electric current at reasonable prices might never have been built were it not for welding.

Welding has been the greatest single factor in enabling the chemical industry to produce products that were unheard of 25 years ago. The tremendous increase in farm products has been helped by welding, in the building of farm tractors and earth-moving equipment.

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A COMPARATIVE STUDY OF EUROPEAN WELDING OPERATIONS

THE AMERICAN POINT OF VIEW

This is a report of the three United States members of a mission which spent four weeks visiting plants and conferring with welding experts in eleven European countries. It attempts to make a basic comparison of European and American welding operations

BY R. W. CLARK, S. A. GREENBERG AND C. E. JACKSON

Fig. 1 View of Pont Cornielle bridge

Origin and Objectives of European Tour

The Organization for European Economic Co-operation, commonly called OEEC, was founded by the Western European nations to provide a means for the free exchange of technical and economic information obtained in each member country. The United States and Canada are Associate Members.

The European Productivity Agency, EPA, is one of the divisions of OEEC, primarily concerned with providing information which will improve the economic status of European countries through increased productivity—that is, a more efficient, less costly manufacture of products. The program of EPA is largely carried out by experts or organized study teams. Through tours, visits and conferences in different countries, these experts or study groups survey the knowledge, experience and technical facilities pertinent to the particular subject or field of industrial application.

A few years ago a European study group, called a "mission" by EPA, visited the United States to study the welding practices followed in American industry. One of the recommendations of this mission at the conclusion of its visit was that a similar mission of Europeans be organized to tour European welding operations. This was deemed desirable in order to provide a basis of comparison between European and American welding practices. Acting on this recommendation,

R. W. Clark is Welding Engineer, General Electric Co., Schenectady, N. Y.; **S. A. Greenberg** is Technical Secretary, American Welding Society, New York, N. Y.; **C. E. Jackson** is Research Metallurgist, Metals Research Laboratories, Linde Air Products Co., Niagara Falls, N. Y.

EPA Mission 250 was created to make a "Comparative Study of Welding Techniques in Europe."

Organization of Mission 250 was made much easier by the existence of the International Institute of Welding. Being an international affiliation of welding societies and institutes in different countries, IIW obtained the cooperation of each of these national welding organizations in the selection of qualified members for the mission and in the organization of visits and conferences by the mission within the different countries.

Since it was desired to compare American and European welding practices, as well as welding practices among European nations, invitation was extended to the American membership of IIW to appoint three representatives to Mission 250. The AMERICAN WELDING SOCIETY, as one of the three organizations sharing American membership in IIW, designated R. W. Clark and S. A. Greenberg, and Welding Research Council and Ships Structure Committee designated C. E. Jackson. In all, the 29 members of Mission 250 included representatives of fifteen countries as follows: Austria, Belgium, Canada, France, Germany, Great Britain, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Sweden, Switzerland and United States.

OEEC Mission 250 met in Paris on Monday, April 18, 1955, and in the four weeks ending Saturday, May 14, 1955, visited plants and research organizations and conferred with welding experts in the following eleven European countries: Austria, Belgium, Denmark, England, France, Germany, Holland, Italy, Norway, Sweden and Switzerland.

There remains for Mission 250 the task of preparing a report of its tour with conclusions and recommendations as indicated by what was seen.

This is an interim report by the American members of the Mission prepared with a twofold purpose: To provide the American point of view for inclusion in the report of the Mission and to apprise those in American industry interested in the application of welding of what we saw in Europe. The final report of the Mission is expected to include the recommendations of the Mission. The conclusions at the end of this report were independently arrived at by the United States representatives. We believe them to be of particular interest to industry in the United States.

The tour of Mission 250 included visits to manufacturing plants; discussions with welding experts; inspection of fundamental and applied research programs; and the inspection of welded bridges, an oil refinery and a power station already in service.

We want especially to acknowledge the excellent cooperation of everyone concerned. The willingness on the part of each company or group to answer our many questions and the gracious and cordial hospitality extended us in each country and during each visit are acknowledged with sincerest thanks. This friendly spirit has made writing this report easier; even more important, it made us feel at home and erased any possible barriers which might have existed due to our lack of familiarity with languages or customs.

Development of Welding Processes in Europe

It must be considered that the plants visited by this Mission were representative of European practice. As in the United States, the selection of welding processes and techniques for any application is dictated by the product being fabricated, the equipment available, the regulations within a country, the type of labor available, as well as strictly economic considerations. In some of the installations the equipment available for a particular operation might not insure the most economical operation. However, since the cost of labor in Europe is generally low, the urgency for scrapping an existing production setup in favor of new equipment requiring additional capital expenditure is not always great.

It is interesting to note that the number of welding processes actually being used is large. A listing of the welding processes observed follows:

Arc Welding:
1. Carbon electrode, unshielded
2. Metal electrode, unshielded
   - (*a*) bare metal arc
   - (*b*) stud welding
3. Metal electrode, shielded
   - (*a*) covered electrode (short lengths)
     - (1) manual
     - (2) machine { firecracker (self-consuming); "stick feeder" }
   - (*b*) covered electrode (coiled lengths)
   - (*c*) atomic hydrogen
   - (*d*) inert-gas metal-arc
     - (1) tungsten electrode with and without filler metal
     - (2) consumable electrode
   - (*e*) submerged arc
     - (1) single pass
     - (2) multiple pass

Resistance Welding:
1. Spot welding with
   - (*a*) portable guns
   - (*b*) single-spot machines
   - (*c*) multiple-spot machines
2. Seam welding
3. Flash welding
4. Projection welding

Thermit Welding (nonpressure)

Gas Welding (oxy-acetylene)

Forge Welding

Brazing:
1. Torch
2. Dip
3. Induction

The arc-welding machines are generally single-operator units with a high degree of portability. This is equally true for a-c and d-c welding. Single operator machines generally are of 300 to 400 amp capacity, although one shipyard installation consisted of twelve 900-amp generators. The largest single unit of power

Fig. 2 Use of continuous coated electrodes

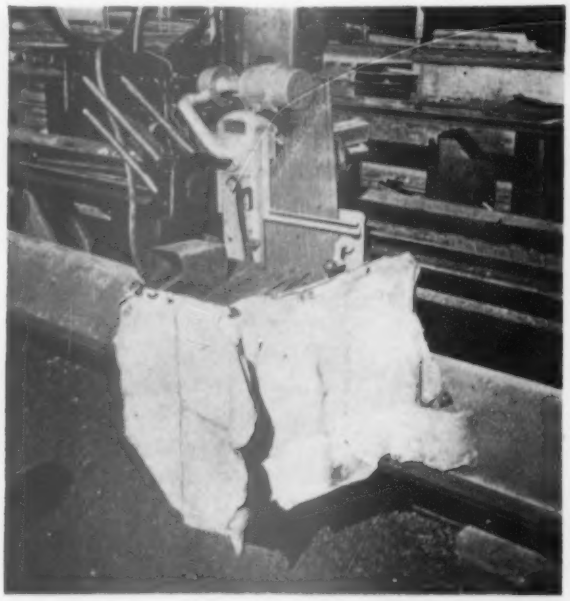


Fig. 3 Use of automatic stick feeder

seen for heavy submerged arc welding was 15,000 amp. One application with multiple electrodes using very high currents (over 4000 amp) for submerged arc welding of heavy steel plate was observed. However, the usual power supply seen for submerged arc welding is 900 amp.

Light-weight readily portable oxygen-cutting equipment is widely used for straight line plate preparation and convenient accessories are used for manual shape cutting. Other installations seen for plate preparation include elaborate multiple torch machines with template control. Multiple torch setups are also used for plate edge preparation of special bevels. An "electronic eye" control unit was seen used in a few installations. Practically no stack cutting was noted. While some use of propane was noted, acetylene is the most commonly used fuel gas.

The speed of welding seemed to be generally slower than in the United States. Some of the positioning and handling equipment seen was outstanding. We estimate that over 90% of the welding observed was done downhand. Equipment for mechanically feeding covered electrodes from a magazine was used to an advantage in a few specific applications. A machine welding process using continuous coils of covered electrode was seen used frequently for long multiple pass seams. Auxiliary equipment, such as cables and electrode holders, is much like that used in the United States.

As in American practice the most widely used process is manual metal-arc welding with covered electrodes. Submerged arc welding is used extensively in welding plate and longitudinal and girth piping seams. Three applications of a process known in the United States as "firecracker welding" were observed. To us, it appeared that this process was slow if considered in the light of other available machine-welding processes. A fair number of applications were noted using a continuous, coated electrode (see Fig. 2) and several applications were noted where mechanical equipment for feeding manual covered electrodes was used (see Fig. 3). This last process was used in at least one application with regular short lengths of a low-alloy steel covered electrode to obtain improved low-temperature properties in the deposited metal. Inert-gas metal-arc welding using a tungsten electrode was seen used, either with or without filler metal, in those few instances where we saw the welding of aluminum. Argon is used exclusively since helium is not available in Europe. On the basis of initial experiments interest is developing in the use of the consumable electrode method for welding aluminum, although only two applications were noted on this tour. No application using submerged arc welding of steel sheet metal was observed.

In general it can be said that the welding techniques employed in Europe compare favorably with the standard practices used in America.

Labor and Management

Labor costs in Europe are low and material costs are high when compared to the United States. As an example, a Director of a German company stated that the saving of one ton of steel justifies the use of up to 80 man-hours of labor. Before the war this ratio was 1 to 40 in Germany. He gave a ratio of 1 ton to 20 man-hours in the United States as his figure for comparison. He further stated that this situation favored light-weight design and the use of welding. By this approach this company realized a material savings in a medium-sized harbor crane of 15 to 20% in 1944 over 1924. In a 1955 design another 40% has been saved.

Fig. 4 Use of handshield (note cigarette)

In all of the eleven countries we visited, employment was high. Welding is used very extensively to save steel as well as to reduce weight. A great deal of time is spent in design and planning. It is common practice to use sheet and plate fabricated into shapes best suited for each structure by oxygen cutting, forming and welding. Management appears to be fully aware of the importance of quality control in welding applications.

Generally, supervision of welded construction is handled by technically competent welding engineers and welding supervisors who have been trained in both the practical and technical phases of welding (mainly arc and gas welding). Generally the workmanship is good indicating proper control of all factors involved in the applications of the welding processes. European industry is fully aware of technical developments in welding applications in the United States.

Welders are generally paid by the hour or on an individual piece-work basis. There is very little use of group incentive systems. In some plants bonuses are paid quarterly or yearly based on output or earnings. It appeared in general that rather narrow ranges of extra pay are used for efficiency. When considered as incentive plans to increase productivity, the European plans we encountered do not appear to us as effective as many of the incentive plans used in the United States.

It is very common in Europe for all tradesmen to have apprentice training, including both schooling and practical training, and to pass tests before becoming qualified to practice their trade. Generally this practice applies to welders also. It is also very common to retest welders every two years. The welders' tests are basic tests used for screening purposes.

Industry in Europe appears to recognize that the broad aspects of using welding involve suitable design, manufacturing processes and quality control. There are many countries where industry has sponsored and supported laboratories and institutes which assist in solving their problems with application of the welding processes.

An example is the Central Welding Institute of Denmark which does X-ray inspection of welded joints in each sponsor's plant twice a year without advance notification. Production welds made by each welder are X-rayed and all welders are classified. A running record of all welder classifications is furnished the manufacturer. Also as they find welding of questionable quality they determine the cause—which may be the welder, material preparation, assembly or design—and inform management accordingly.

The many institutes of welding in Europe are not promoting joint welding procedure qualification as such but rather assisting industry in the application and control of all factors involved in the application of a welding process to specific applications. They question the great emphasis placed on welder and procedure qualification in the United States and our lack of consideration of other factors involved in the application of welding.

These institutes also assist industry in the interpretation of codes, such as ASME or ABS, which is not always simple. They also evaluate new welding equipment and processes when requested.

While one of the main purposes in using welding in Europe is to conserve material, at the same time by proper design and quality control they have also obtained reduced product cost.

Health and Safety

Health and safety in welding are of far less concern in Europe than in the United States, assuming what we saw and those with whom such matters were discussed are representative.

In only few shops are ducts used for exhausting the air at welding stations. However, a majority of the shops seemed to be free of fumes and smoke, adequate ventilation being provided by the natural flow of air.

Fumes are of little concern but this is probably due to the fact that the greatest amount of welding by far is done on carbon and low-alloy steels with gas welding, shielded metal-arc welding or submerged arc welding. In one shop where inert-gas metal-arc welding was in progress, ozone was present in sufficient quantity to be mildly irritating.

Except in one plant visited, there was no use made of curtains or screens to shield nearby workers from the rays of the arc. It is common to see one welder cleaning a weld in very close proximity to the bright arc of another welder making a weld.

The welders themselves, of course, use eye protection during welding. For gas welding and cutting, goggles are used, much like those used in the United States. It is interesting to note, however, that for shielded metal-arc welding, hand shields seemed to be preferred over helmets in all the countries visited except Norway (see Fig. 4). Both helmets and hand shields were seen used, sometimes in the same plant, in Denmark and Switzerland. Where nonconsumable inert-gas metal-arc welding is used, a changeover to helmets has been necessary.

A general preference is indicated for d-c welding over a-c welding in all countries except Sweden. This was explained on the basis that the shock hazard with d-c is less than with a-c. In Germany, government regulations actually prohibit the use of a-c for safety reasons in pressure vessel fabrication and shipbuilding, the two industries covered by government standards.

Oxygen cutting operations, almost without exception, are done with a far greater rate of oxygen consumption than is normal in the United States. Contrary to safety recommendations in the United States streams of sparks flew in all directions and for considerable distances. Comment on this on several occasions did not seem to arouse the concern of anyone.

Inert-gas metal-arc welding is only just beginning to be used in most European industry and the safety aspects of this process have been given little consideration to date. A study has begun in England under the sponsorship of the British Institute of Welding and in this connection there was interest shown in the study completed by the American Welding Society last year.

Welders seem to be clothed in a manner which would conform to American standards of safety, with long sleeves, heavy shirts, heavy shoes and cuffless trousers.

An interesting device for detecting the presence of gases in an atmosphere was demonstrated in Germany. This seemed to be a good means for checking the contents of a container or tank which had previously held combustibles and was to be welded or cut. The device consists of a bellows by means of which an air sample is drawn into a glass tube. The glass tube contains crystals of a chemical which changes color in the presence of a specific gas, different tubes being available for different gases. Each tube is graduated and the proportion of the gas under question present in the air sample used can be read directly.

On the whole welding shops were unusually clean and orderly by United States standards, minimizing the possibility of fire.

Very little evidence was seen of safety posters or any special awareness of the need for safety. First-aid kits were practically nowhere in view.

Standard Specifications and Quality Control

European standardization activities are following a pattern closely comparable to the earlier experiences with standardization in the United States. Standards are being developed as the need for them is indicated. Currently the need appears to be greater and the standardization activities have increased accordingly.

Such standards as do exist are seriously lacking in uniformity from one country to another. However, steps are being taken toward effecting agreement through OEEC activities and through such organizations as the International Institute of Welding and the International Standards Organization of which Technical Committee 44 deals with welding.

New standards will probably be more uniform because of these organizations and because their activities will provide a means of interchange of ideas between participating countries, much like AWS and the other national welding organizations provide within their respective countries.

At present standardization is most extensive in those industries where the government is the prime customer. Railroads, shipbuilding and bridge construction are the most notable examples. Standard specifications in these fields vary as to the extent of

detail. In many cases they are detailed purchase specifications; in other cases the specifications or standards are broad basic definitions of design, material, fabrication requirements and inspection.

The following itemization of standards in the countries visited is by no means complete. It represents only that information which was obtained by the American representatives during the trip.

In France, government specifications or standards cover the fabrication of bridges, railroad equipment, pressure vessels and ships. These are prepared by commissions serving under a government agency. The French Institute of Welding is represented and cooperates in these activities. It also issues some recommended industrial standards of its own.

In England there are recognized industrial standards apart from those issued by the British government for its own facilities. These are issued by the British Standards Institution, with the Institute of Welding cooperating in their formulation.

In Germany, the Deutscher Normenausschuss issues the well-known "DIN" (Deutsche Industrie Normen) standards for different industries. Such DIN standards are available for pressure vessels. As in other countries bridges are built for the government and made under government specifications.

In all other countries visited no information was obtained to indicate the existence of standard specifications, except for government purchase as previously mentioned.

As in the United States, the larger companies in Europe formulate standards of their own for purposes of quality control. Where standard specifications exist, these company specifications are in agreement with them.

Base metal requirements are not usually covered by standard specifications. Steel is purchased on the basis of mechanical properties, chemistry, trade name or a standard means of identification.

Electrodes are covered by standard specifications in Germany for bridge and building construction. Industrial standard specifications for electrodes are widely used in England. In other countries it appears to be the general policy to use electrodes of a given brand with little or no interchangeability. In only one instance, in France, was there evidence of a familiarity with American Welding Society or other United States standards. This plant was engaged in the fabrication of pressure vessels for an American customer under the API-ASME Code for Unfired Pressure Vessels for Petroleum Liquids and Gases. This company also follows the ASME Boiler Code.

Probably due to the absence of general industry standards, quality control, it was found, is usually based on practices established by each company. Greater stress is placed on design, workmanship, training and supervision, with less emphasis on metallurgy and qualification than in the United States.

Joint welding procedures were used as established by a company's engineering staff and qualified for its own information rather than to meet regulatory requirements. The same is true of inspection and testing of finished weldments, although in some cases such inspection is prescribed by the customer.

In general the test methods used are similar to those used in the United States for similar applications. In structural welding, for example, visual inspection is usually considered adequate. For pressure vessels and piping hydrostatic and air pressure tests are used, the test pressures being one and one-half or two times the design pressure. In this field radiography is also used extensively. In addition to X-rays, all of the available isotopes, including radium, cobalt 60 and cesium 137, are used for radiography in different plants. One plant in England had all these sources.

The use of ultrasonic waves was being studied in Britain and France. These studies include the use of a single probe for weld inspection. In only one plant, in Switzerland, was actual use being made of this process for weld examination. This company has developed a method using a single probe and a specially designed template by means of which a weld defect can be readily located when detected.

For resistance welding, in the fabrication of automobile bodies and railroad car sides and roofs, the peel test is used by one company and the tension-shear test by another. As in the United States, these tests are made at prescribed intervals, such as the start of each day, as a control on the machine settings and operation.

Spot weld appearance seemed to be of less concern than it is in the United States. This is probably due to the more usual use, in Europe, of painted mild steel rather than stainless steel or aluminum for railroad cars. Welds on automobile bodies showed equal amounts of indentation or excessive burning, but were not as conspicuous in the finished car, many of the seams being obscured by moldings or the configuration of meeting parts.

There was ample evidence to indicate that European industry is fully cognizant of all factors involved in quality control. The judicious use of quality control measures is well demonstrated by the general high level of weld quality observed.

Productivity

Many new, rebuilt or modernized plants have been planned with material-handling facilities and processing equipment for line production similar to plants in the United States. We were impressed by the fact that the European countries have up-to-date technical knowledge and experience in applying arc- and gas-welding processes. Should it be necessary to meet the market demands for their products either at home or abroad there is the know-how in Europe to effect labor saving and make greater use of automatic equipment (see Fig. 5). To what extent European productivity is increased will depend on economic conditions in each country and the world.

Training of Welders in Europe

In most of the countries, programs for training and

qualifying welders were described. In many of the countries training is sponsored and directly supported by industry. Apprentice training is a part of most fabricating shops, with training varying from two months up to five years. In the three- to five-year programs, an extended period of shop service is associated with the actual training. In England, one company estimates that it costs $100 per week to train a welder in a plant, including salary. Indoctrination of all new welders, and welders used on new applications was generally observed. Use is made of symposiums, panels and regional technical meetings for distribution of information to engineers and other interested personnel. One college course was described which provides a class in welding engineering as part of a course in mechanical engineering.

In France, the Institute de Soudure has organized a training program for welders and supervisory personnel. This organization presents a course which leads to a professional certificate. The regular training courses are under the guidance of the National Education Ministry; shorter courses, of one week to two weeks' duration, are arranged at the request of industrial concerns. The cost of instruction in this case is partly paid by the student or his sponsor, the balance being paid by government funds. The three-year course includes studies in physics, chemistry, electricity, mechanics, metallurgy, mathematics, as well as design and practical welding. Other courses, of one week to two years' duration, are provided for welders and other artisans who wish training in welding.

One French plant has twenty welding stations for training welders. This is operated for two shifts and continued for three to four months. Another plant gives specialized training based on an American text, and continues this training for approximately two months, after which the men who qualify are given further instruction while being used on the job as tack welders.

In England, extensive apprentice and on-the-job training is provided by industry. This is coordinated, through the British Institute of Welding, with the activities of the City and Guilds of London Institute.

The training of welding engineers is the subject of a current study by the British Institute of Welding. For the most part today, welding engineers are civil, mechanical or electrical engineers who have specialized in welding in industry. The British Institute of Welding is active in getting the universities and technical colleges to include welding courses in their curricula. A conference is being planned for 1956 on the place of welding in technical education which will consider the role of the welding engineer in industry, the type of education required by a welding engineer and the means of providing such education within the present educational system.

In Norway and Sweden apprentice systems have been set up giving training in various plant operations to the workmen. These activities include training in welding.

In the Netherlands, welders are trained in one plant by instruction on the job. Selected men are given a minimum amount of training and then used on minor jobs and for tack welding, until a proficiency in welding is developed. The Netherlands Welding Society also conducts training courses for welders and engineers.

In Germany, welders are trained in the plants, with a certificate being issued to those qualified by German Lloyd's or Technischer Uberwachungs Verein, depending upon the type of work being performed. The Schweisstechnische Lehr- und Versuchsanstalt and other industry-supported schools also train welders in Germany. There are four or five such schools in different parts of Germany. Students are usually sent to the schools by industry, who pay the fees and expenses of the students. Training is also provided for upgrading of the workmen.

In Austria, the Central Institute for Welding Technique is mainly interested in the training of welders, welding foremen and welding engineers.

In Italy, the largest number of welders are instructed and examined by the plants themselves. Schools at Milan and Genoa hold classes four evenings each week for six months, giving 100 hours of theory and 80 hours of practical welding. At the end of the course, a special commission, including state representatives, examines the students. When qualified, the student is given a certificate of specialization in welding. The welders for various industries, such as shipbuilding, are examined and their qualifications noted by a special board.

In line with the general policy of apprentice training in Europe, it was our impression that more consideration is given to training welders in Europe than in the United States. The same can be said for the training of welding engineers and foremen.

Research in Welding

Most of the research work in welding in Europe is closely associated with improvement in use of the weld-

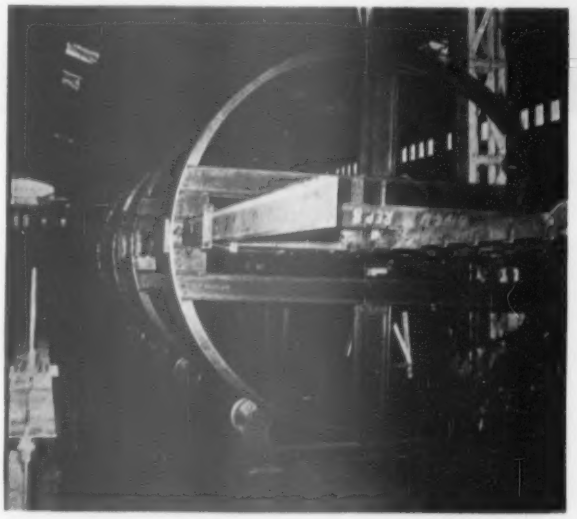


Fig. 5 Positioner for railroad car underframe

ing processes or of welding techniques, rather than with fundamentals. As might be expected, research in the different countries is unrelated. It seems best, therefore, to report on the research facilities in the order in which they were visited.

At the Institute de Soudure in Paris we saw the following studies, among others:

Metallizing with aluminum on rimmed steel plate to reduce porosity during inert-gas metal-arc welding. Approximately 0.30% aluminum appears to be sufficient according to their latest findings.

Use of a hot air torch for the welding of plastics. A polyvinyl plastic was being studied.

A weldability program using the Kinzel test at a temperature of −60° F. Present studies are confined to base metals.

At the Manchester College of Technology, in England we saw studies involving

Damping of welded structures
Lattice column design
Influence of oxygen cutting for edge preparation on fatigue of weldments (see Fig. 6)
Photoelastic studies of design variations
Fatigue of heavy welded chain

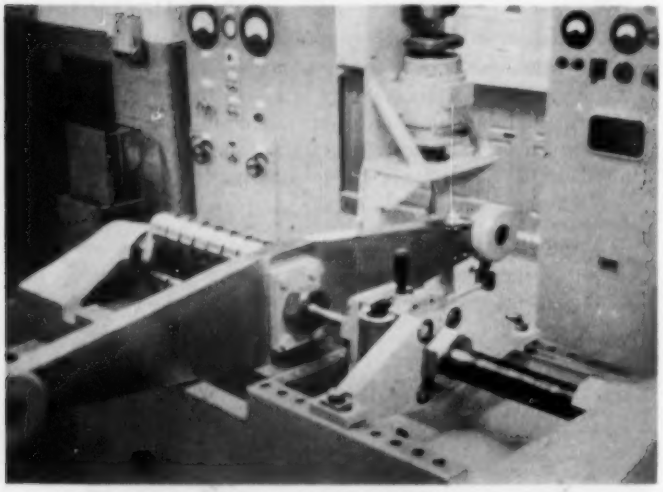


Fig. 6 Fatigue testing machine

The activities of the British Welding Research Association are carried out in two laboratories, one at London devoted mainly to metallurgical studies and the other at Abington (near Cambridge) where we saw

A fatigue program intended to evaluate the behavior of butt joints in structural members. A 100- to 200-ton machine was being used to apply a pulsating tensile load to steel plates $^1/_2$ to $1^1/_4$ in. thick. Similar testing is being performed on welded piping. Confirming previous findings in the United States, the results thus far show the importance of geometry of the test specimen on its fatigue behavior.

The usefulness of tri-form or collar reinforcements in Y-connections is under study for heavy wall pipe of 8-in. diameter. The stress is determined in the welded joints by means of SR-4 strain gages.

In a study of brittle fracture, a number of different types of test specimens are being investigated, including a repetition of Doherty's large-scale bend test.

Other programs of investigation include the efficiency of oxygen cutting; potential use of ultrasonic equipment for weld examination; instrumentation for resistance welding.

In addition to a number of development and control problems in connection with the manufacture of electrodes, research is being carried out in two fields at Elektriska Svetsnings A.B. in Sweden:

Brittle fracture under tensile loading using a specimen with a castiron weld deposit along both edges as a crack starter.

A special hardenability test using a high-frequency unit for heating and a water bath for cooling a small specimen at a rate similar to that encountered in the heat-affected zone during an arc-welding operation. By such test it is possible to measure one of the important factors in evaluating the weldability of a steel.

At the University of Ghent in Belgium we saw several programs under investigation:

Brittle fracture in a large-scale test piece with a biaxial load being applied on a 800- x 8-in. test section. In the cruciform-shaped test piece three of the stressed corners are heated by small torches to prevent failure. The fourth corner is cooled by liquid air to the desired temperature to control the location and nature of the failure. The type of fracture and the propagation of brittle failure are a measure of the properties of the steel. Many Robertson's test pieces are being studied for reference.

Fatigue behavior of welded rails is being studied under simple beam loading. Additional fatigue testing is under way.

At the Association des Industriels de Belgique in Brussels two large testing machines were of interest.

The first of these is a horizontal compression-tensile unit with a specimen length of 65 ft (20 meters). The capacity of this unit is 1000 ton compression and 800 ton tension. The second testing machine is used for fatigue testing a welded cross joint of 16-in. I-beams. The capacity of this unit is 100 ton in vertical loading and 50 ton in all other directions.

Welding Societies and Institutes

One or more welding societies or institutes were found to exist in every country that was visited. The size and functions of these organizations are quite varied. Briefly, this is a report of these institutes in the countries visited in so far as information was obtained.

In France the Institute de Soudure, with a staff of 130, conducts training programs for welders and supervisory personnel, does field inspection of welding on a fee basis and conducts research for product or process development with support from a single company or an industry. It issues a magazine every two months and a series of technical manuals on different welding subjects. A library service is maintained and translations of welding standards, periodicals and articles prepared. Standardization activities are not carried out directly by the Institute de Soudure, but this organization serves in an advisory capacity in this work.

Entirely apart from the Institute de Soudure is the French Institute of Welding Engineers, an individual member society which holds regular technical meetings and engages in other professional engineering activities.

In Britain the Institute of Welding functions as an individual member organization, with a written test required for admission in addition to specific entrance requirements. This Institute has a technical division which maintains a library service, issues a monthly magazine and cooperates in the establishment of training standards for welders. It engages in activities of professional interest, such as the training of welding engineers in colleges, and cooperates with the British Standards Institution in the formulation of standards on welding. Welders are admitted to membership in the Institute according to qualifications established by the City and Guilds of London Institute for the classification of a welder.

The British Welding Research Association was formerly a part of the Institute of Welding but is now operated separately, with close cooperation between the two organizations. Unlike its American counterpart, Welding Research Council, BWRA receives contributions from industry only to its general fund. Research programs are organized and followed by committees with all funds for such work allocated from the general fund.

Of interest in passing is the British Electrical Manufacturers Association, BEMA, which is active in the standardization of electrode classifications.

The Norsk Sveiseteknisk Forening (Norwegian Welding Society) was started in 1932 but has employed a full-time secretary only during the past year. It has begun to issue a regular magazine and work is now under way in the preparation of up-to-date By-Laws defining its operations.

No information was obtained in Sweden concerning the activities of the Svetskommissionen.

In Denmark, the Danish Institute of Welding, DSL, has 400 active members and holds regular technical meetings. The Central Welding Institute of Denmark is a nonprofit organization sponsored by industry for inspection of welding.

The 6000 members of the Netherlands Welding Society are divided into thirteen departments (local sections), one in each province. These members include welding engineers, technicians and welders. A journal is issued regularly and one of its principal activities is the establishment of training courses for welders and teachers of welding. Only recently a Netherlands Welding Research Center has been organized to carry out welding research programs.

In Belgium, in addition to L'Institut Belge de Soudure (Belgian Institute of Welding), there is the Association des Industriels de Belgique, which performs inspections and conducts research programs in welding and many other industrial matters on a fee basis as requested by a company or industry.

In Germany, the welding organization is known as the Deutscher Verband fur Schweisstechnik, with headquarters in the heart of German industry at Düsseldorf.

The welding organizations in Austria interested in welding include Schweisstechnische Zentralanstalt (Central Institute for Welding Technique); Oesterreichischer Gesellschaft fur Schweisstechnik (Austrian Association for Welding Technique); Oesterreichischer Normen-Ausschuss (Austrian Standard Committee) and Oesterreichischer Stahlbau-Verein (Austrian Association for Structural Steel). A monthly publication is issued jointly by the first two of these organizations.

The Central Institute for Welding Technique concerns itself mainly with the training of welders, welding foremen and welding engineers. This Institute also acts as a consultant to industry and by lectures and demonstrations keeps the smaller companies informed of the latest developments.

The Austrian Association for Welding Technique is essentially a member organization.

The Swiss Acetylene Association and the Societe Suisse de Constructeurs de Machines are the two organizations in Switzerland mentioned with respect to welding activities.

In Italy the arrangements for the visits of the mission were handled by the Institut Italien de Soudure, but time did not permit procuring information concerning the activities of this organization.

It is obvious from the foregoing summary of welding organization activities that the information obtained is far from complete. This report is based on information gleaned as occasion provided, either through conversations with staff personnel or members of these organizations or from literature provided. It is important to note that the extent of coverage in any case is not necessarily an indication of the extent of the activities of that organization. We expect that the complete report of the Mission will provide the missing information.

One other fact was apparent in this connection. Each of these organizations is active in the International Institute of Welding. Through IIW the efforts of all these national welding organizations are correlated for the dissemination of joint reports on subjects of mutual interest. Through IIW they also influence the standardization activities of Technical Committee 44—Welding, of the International Standards Organization.

Automotive Products

The extent to which welding is used in the manu-

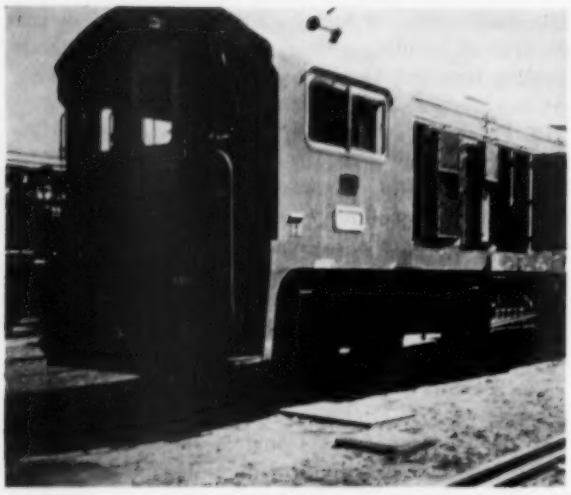


Fig. 7 Typical European diesel locomotive

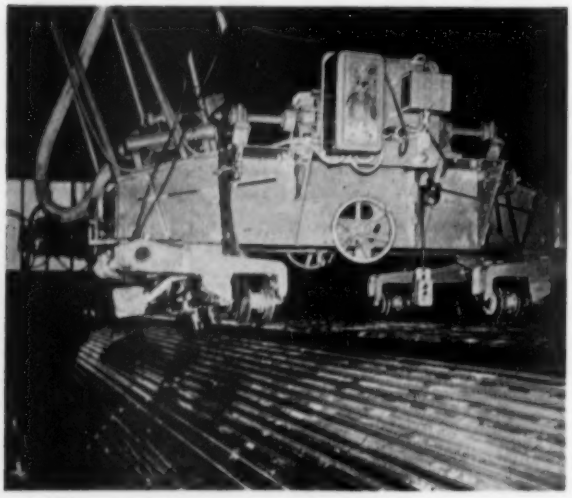


Fig. 8 Seam welding railroad car roof

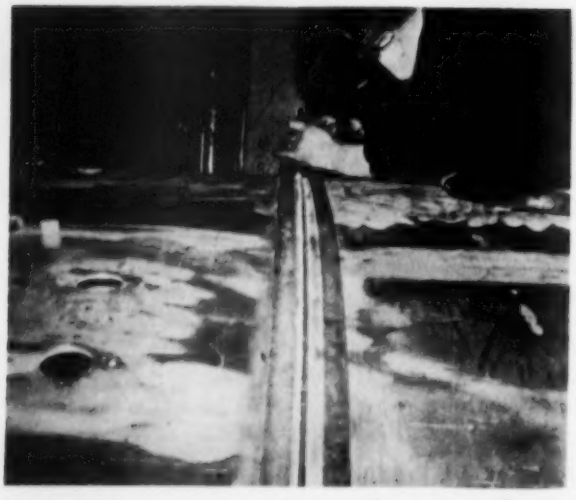


Fig. 9 Inert arc welding with consumable backing

facture of automobiles in Europe differs primarily in the rate of production. The number of welding processes used is large. Where the rate of production is as small as 1000 cars per week there is less use of automatic welding and more handling of the work. Where there is a high rate of production, as in Italy where 800 cars per day are being produced, use is made of automation and mechanical handling.

Plants making automotive products were visited in France, England and Italy. Almost all of the welding processes used in the United States are in use in these European plants. To cite some examples: Bare carbon arc welding is used for automobile frames in one plant; shielded-metal-arc welding in others. Manual shielded-metal-arc welding is used for body assembly and for the attachment of miscellaneous fittings and brackets. Because of the lower production rates this process is used for body assembly to a greater extent than in the United States. This is not to say that the more usual United States practice of using spot welding is not followed. As a matter of fact the Italian plant had multiple spot-welding machines which make up to 50 welds per assembly.

Much like in the United States flash welding is used in the Italian and French plants for fabricating rear axle housings. Use is made of this same process for joining two formed halves of a wheel rim. One plant in England uses manual metal-arc welding for welding rear axle housings. Another plant in England uses a machine welding setup by which welds on opposite sides are made simultaneously using coiled, covered electrodes. In all cases extensive jigging is used to align the parts and position the work.

Seam welding is used for making gasolene tanks, but the rate of welding is much slower than the 800 in. per min achieved in one automobile plant in the United States. In one plant visited induction brazing is used to attach fittings to these tanks.

All of the above-cited applications involved the use of a low-carbon steel. However, in a French plant automobile bodies are being fabricated of aluminum using inert-gas metal-arc welding.

Railroad Cars and Maintenance

Railroad car and locomotive builders (see Fig. 7) were visited in France, Belgium, Netherlands and Norway. The shops of a railroad were visited in France.

Rails up to 800 meters (2625 ft) in length are being flash welded in the shop. Thermit welding is being used in the field to make continuous rails, similar to the practice followed in the United States. In France passenger cars of stainless steel are being built following American practices very closely. In some of the other countries passenger cars are made of mild steel. The main structural members are manually arc welded and the car sides and roofs are resistance welded to the frame (see Fig. 8). Far less attention is given to avoiding indentation and surface marking since in the course of painting such markings are eliminated.

In Belgium one plant is fabricating diesel locomotives

according to an American design. Another Belgian plant is making railroad passenger cars using steel for the framing and aluminum for the sides and roof. Seam welding and inert-gas metal-arc welding using a nonconsumable electrode is used. For joining the roof a filler metal which is formed to serve as a backing as well is used (see Fig. 9). This is similar to filler metal introduced for welding stainless-steel piping about a year or so ago in the United States.

The plant in the Netherlands makes both locomotives and passenger cars. Processes used include shielded-metal-arc welding and to a lesser extent submerged arc and spot welding. Submerged arc welding was being used on metal 0.20 in. (5 mm) thick. This is the thinnest material we saw being welded by this process. Production in this plant is at a rate of twelve passenger and freight cars per week.

As much from riding in European coaches as from visiting these plants, we were impressed with the fine styling and craftsmanship of these cars. Much of the rolling stock is excellent, with quiet operation and smooth performance.

Shipbuilding

In Europe, all the shipbuilding yards which we visited were busy. The practices and techniques of ship construction, in general, were similar to those used in America (see Fig. 10). Extensive use is made of oxygen cutting equipment for plate preparation, together with modern automatic submerged arc equipment and a weldable steel.

In Sweden, one of the largest yards was visited. Much of the yard is new, with new shops and increased acreage being obtained during the past decade. Production in the new yard begins in a plate shop with equipment and space fitted for work on plane plates, curved plates, profiles and framed sections. These plate shops are convenient to the welding shop, where the pieces are joined into sections weighing up to 40 tons. Shop welding is largely done by the automatic submerged-arc welding process. The welding shop is adjacent to three concrete berths, each capable of accommodating hulls up to 35,000 tons dead weight. The use of prefabricated sections speeds up the assembly on the berths so that an 18,000-ton tanker requires a building time on the way of three months or less, using manpower on only one shift. Welding on the ways is done with stick electrodes, either manually or by machine welding.

In Denmark, the mold loft of a shipyard we visited uses a large-scale projection of the drawings from which the sections are directly laid out on steel plate. Films

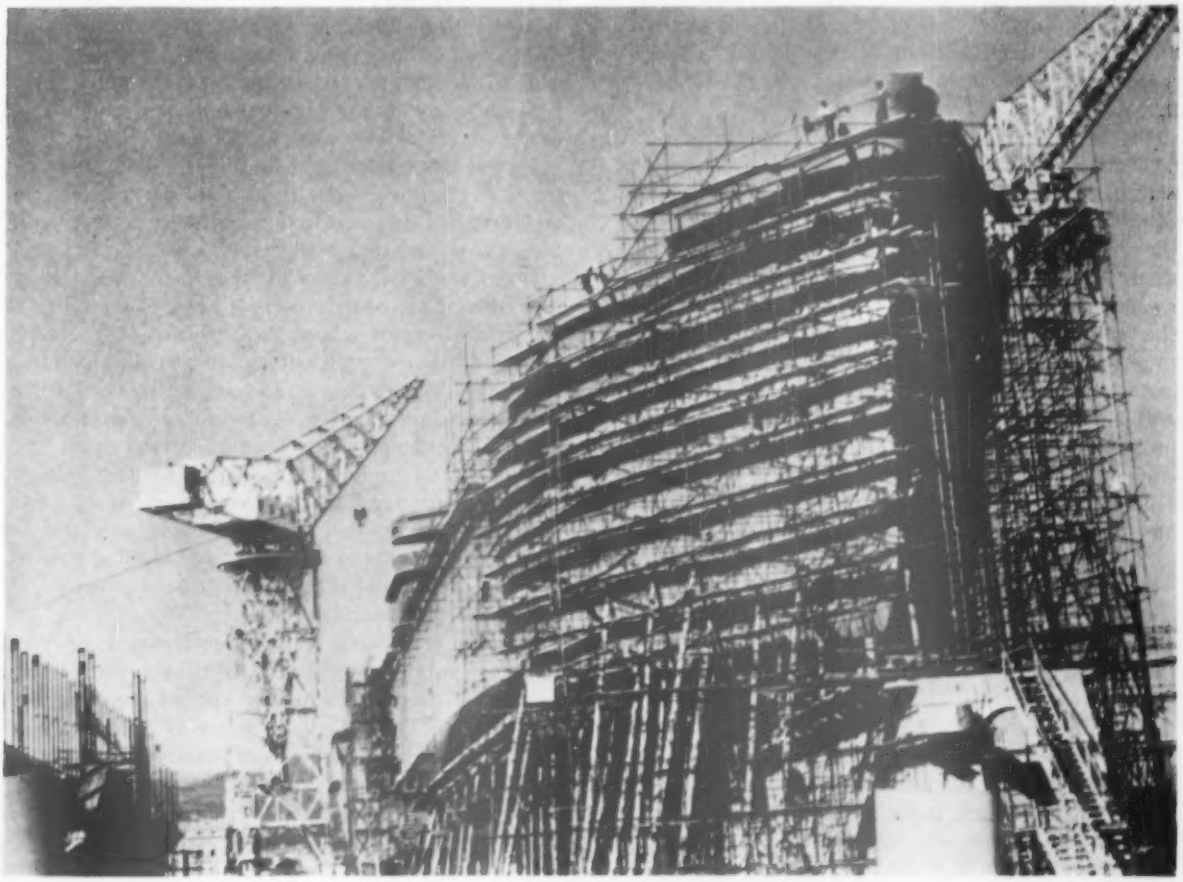


Fig. 10 All-welded tanker hull

Fig. 11 Submerged arc welding deck plates

Fig. 12 Welded ship hull on ways

with carefully scaled drawings are used in a very large projection room, and the lines on the plates marked with a punch without any further scribing. Heavy shearing equipment permits high-speed bevel cuts being made in 40-ft long, 1-in. thick plate. Automatic submerged-arc welding equipment and improved handling facilities reduced the labor in this yard to approximately 180 man-hours per net ton of steel in a tanker or cargo vessel.

In the Netherlands, a yard was visited which had 6000 employees. Much of the plant construction is new, having been built after the last war. The capacity of the yard has been increased from 15,000-ton before the war to a present size limit of 27,000 tons. Automatic submerged-arc welding is used in the shop assembly of plates (see Fig. 11). In order to improve the safety of the service of some of their vessels, a proprietary low-temperature steel is being used in certain critical midsection areas.

One of the smaller yards visited in West Germany is probably typical of such yards in Europe, having 450 employees of which 50 are welders and 32 salaried personnel. Eighty percent of the effort is directed toward new work and 20% to repairs. In 1946 this yard scrapped all riveting equipment so that future work would be carried out entirely by welding. It was stated that this conversion was made in spite of the fact that at first the cost of welded construction was higher than for the previous practice of riveting. All welding in this yard is manual since they do not have confidence in using the automatic processes in construction carried out in an open yard (see Fig. 12). No shelter is provided for any of the construction in this yard. Tankers up to 1400 tons are being built. The yard has 15 berths and a special side launching setup which provides ready launching of the small ships into the water.

In an Italian yard, it was stated that they began using arc welding in ship construction in 1927. Welding has continued to be used since that date in order to give them lighter structures. This particular yard used approximately 135 tons of steel per day, and has a total of 4800 employees. A very unusual handling system with overhead cranes on overhead cables gives this yard flexible control in a space 682 ft (210 meters) wide, 975 ft (300 meters) long and 221 ft (68 meters) high.

Machine welding is performed with a minimum of protection from the weather. A very elaborate installation is used for mechanically cleaning plate surfaces by blasting. Prefabrication of parts is done for about 80% of the construction of vessels in the range of 25,000 to 31,500 tons dead weight.

One of the oldest yards in France was visited. Large tankers were stated to be built at a cost equal to that of the Swedish yards (about $130 per ton). The claim was made that oxygen cutting and welding permit a small yard to become a large yard. This yard, it was stated, welds 90% of a tanker in the flat position. Automatic submerged-arc welding is used in an open yard with no protection from the weather. Flame cleaning is used immediately prior to painting. Subassemblies are made in spacious shops available for plate preparation and automatic and manual welding. A 90-ton field crane is available for use in assembly of the prefabricated sections (see Fig. 13).

The use of welding in the shipbuilding industry in Europe is firmly established. All the shipyards visited have extensively and carefully applied the techniques of welding. The extent of the use of automatic submerged-arc welding ranges from zero to more than 60% of the completed structure. The extent of preassembled shop welding ranges up to 80%. The materials used consist of low-carbon, killed steels, which reflect a practice aimed at greater resistance to brittle fractures. Since 60% of the steel made in Holland, for example, is

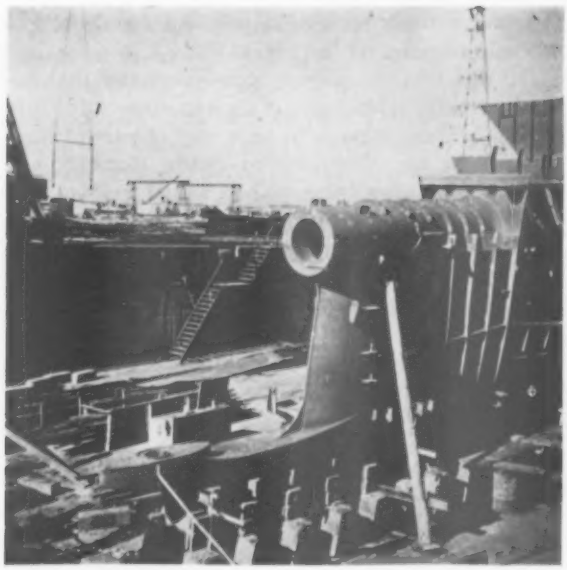


Fig. 13 All-welded stern frame assembly

Fig. 14 All-welded Bessemer converter

used in shipbuilding, the steel can be more closely produced specifically for shipbuilding than is possible in the United States.

Machinery Fabrication

Very extensive use of welding in machinery fabrication was seen in England, Norway, Denmark, Belgium, Germany, Austria, Switzerland and Italy. It is evident that the high cost of steel and a low labor cost are very important factors in this extensive use of welding in fabricated structures throughout Europe.

It appears that in general the carbon steels used in these welded structures have a lower carbon content than similar steels in the United States, the carbon content being 0.23% max in Europe as compared to 0.30 to 0.35% max in the United States. Except for light-weight and low-stressed structures, where rimmed or Bessemer low-carbon steel is used, either aluminum or silicon killed open hearth or electric furnace steel is generally used. European silicon killed steels contain from 0.25 to 0.35% silicon as compared to 0.15 to 0.30% in the United States. In Austria, the oxygen process, basic Bessemer steel, is being promoted for welded structures. In all of these steels there is a tendency to keep the carbon under 0.23% and use manganese in a range of 0.90 to 1.00% to maintain minimum mechanical properties.

Low-alloy steels are used for fabricating steam turbine rotors and gears. These contain 0.23% carbon max and up to 1.5% manganese and 0.25% vanadium.

On heavy, important machinery structures, basic (lime-covered, low-hydrogen) electrodes are being used very extensively. In some cases these electrodes are being used for the first pass of fillet welds and in other cases for the entire weld. This type of covering is used in all cases that we saw involving alloy steel electrodes.

Very extensive effort is being applied to design to reduce weight and conserve steel. Formed sections from sheet or plate are used, with extensive use of stiffeners in all machinery. This is particularly true in the plants visited in Germany and Switzerland. As an example, in Germany Bessemer converters (see Fig. 14) and electric furnaces are being fabricated with radical changes in design. In Switzerland and Italy steam turbine rotors are being fabricated of small forgings welded together because of the cost and weight limitations of large forgings. This type of construction also permits the use of more than one steel composition in the same rotor based on temperature requirements for specific parts.

In Italy, welded gears for marine applications are made using carbon steel for the web and a manganese-vanadium alloy steel for the rim. Small castings are used to advantage in fabricated structures, such as bearings used in gear casings and fabricated turbine casings. A stress-relief heat treatment is used only where dimensional stability is required.

In Germany, one company stated that all of their welded designs are checked to insure that they will meet service requirements by stress analysis and by load testing using strain gages. This method has assisted them in producing very light-weight structures, thereby saving steel and reducing the total weight of the product. It is interesting to note that this effort to save steel has, at the same time, resulted in lower total product cost.

While manual shielded-metal-arc welding is used very extensively there is evidence that mechanized welding processes are being applied where it is practicable to position and rotate the work. Practically no semi-automatic welding processes were seen in use. Submerged-arc welding, both single and multiple pass, appears to be used most extensively. Multiple-pass submerged-arc welding was seen used in welding alloy

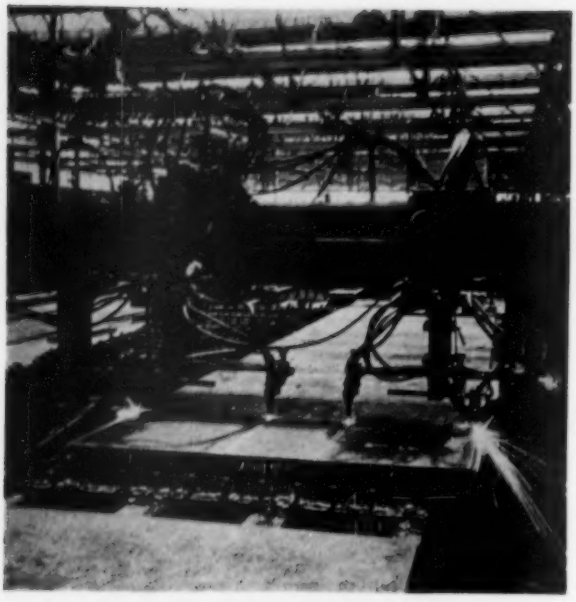


Fig. 15 Mechanized multiple torch cutting

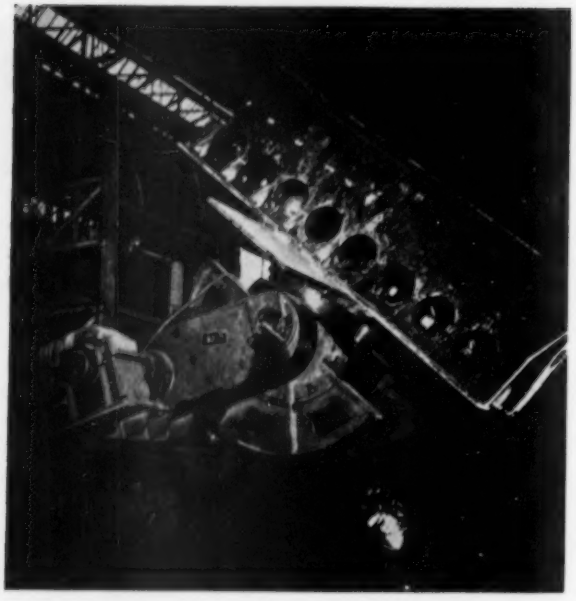


Fig. 16 Positioner for welding diesel frame

steel turbine rotors in Switzerland. A similar application involving only one welded joint per rotor is welded manually in Italy. The mechanized arc-welding process using continuous coiled covered electrodes is also being used quite extensively in one or two plants where production is limited or alloy steels are being welded.

Mechanized oxygen cutting is being used extensively in plate preparation and shape cutting. While manually guided torches and mechanized single torches are used and produce good edges, there is considerable use of multiple torch machine oxygen cutting for shapes and edge preparation (see Fig. 15).

Based on what we saw our impression is that management has a full appreciation of the importance of quality control. There appears to be a very effective follow-through in manufacturing to insure that material preparation, assembly as well as actual welding conforms to the design requirements. The use of nondestructive tests for quality control depends on the service requirements of the product. Such tests appear to be used not only for final inspection but to assist in supervision and quality control during fabrication.

Visual inspection was the most extensively used nondestructive test but we saw some magnetic particle and liquid penetrant testing of welds in marine diesel frames, turbine rotors and welded gears. While radiography was not being used very extensively for machinery fabrication, it was used in a number of applications for quality control purposes.

It is our impression that workmanship in manual welding is generally better than in the United States. The lower cost of labor and a fuller consideration of quality control may partly account for this.

Very little, if any, difference was noted in workmanship in the application of mechanized welding processes. As in the United States, in some plants emphasis is placed on keeping weld reinforcement to a minimum. In the machinery fabrication we saw, the preparation of material and the control of setup during assembly were held to a very high standard and again are better, on the average, than would be found in the United States.

A great deal of time is spent handling materials manually. However, there is evidence of great improvement in this area, even in the older plants. The new plants are well planned with very good crane facilities. Jigs and fixtures (see Fig. 16) are being used very extensively. They appear to be able to extend the use of these facilities and reduce the labor content when and if required by economic conditions.

In Denmark, a plant fabricating diesel bases and frames is using large motor-driven positioners to position complete assemblies for manual metal-arc welding. Rotors in Switzerland and Italy are positioned for mechanized welding. In Germany where they are fabricating Bessemer convertors and electric furnaces there was very little positioning because of the size of the assemblies and in this case there was considerable manual welding in the vertical position.

The high cost of steel and the lower cost of labor in Europe as compared to the United States have resulted in very extensive use of welding for fabricating machinery. This has resulted in products of lower weight, which is an advantage in many cases from the standpoint of power required in service as well as in the handling during production. Furthermore, use of welded designs has generally reduced the over-all cost of the product. It appears that Europe is very effectively applying their know-how in fabrication by welding to produce high-quality machinery structures which

are competitive with the United States.

Structural Steel

Welded structures comprising buildings, bridges and handling equipment such as cranes, derricks, shovels, etc., were inspected in service or during fabrication or discussed with welding experts in Belgium, Germany, Holland, Italy, France, Austria and Norway.

In bridge construction the general practice has become to shop weld using riveting or field welding for erection, according to the specific experience and economic considerations of the particular fabricator. Railway bridges, like in the United States, are not usually welded, although strengthening and repairing, probably by necessity, are more usually by welding.

Among the notable examples of welded highway bridges inspected were three which span the Seine River near Rouen, France. The Pont de L'Arche Bridge located at the junction of the Seine and Eure Rivers is 1100 ft (368 meters) long, said to be the longest continuous span in Europe. The second bridge in this group is the Pont Corneille Bridge (see Fig. 1) located in Rouen. It is a continuous arch bridge of two equal spans with a total length of 930 ft. Nine box girders are used to provide a four-lane highway bridge. The steel used is of fully killed open-hearth quality with a chemistry of 0.16 C and 0.50 Mn max., the tensile strength being 55 to 70,000 psi. The construction appears to be massive for the type of loads carried, but in the course of examining European bridge practices, it was found that there is a preference for thinner and shallower members and use of a greater number of girders with rather common use of box-girder sections for heavy bridges. Thicknesses of 2 in. are uncommon and could be considered maximum as compared to the use of flanges of 2 in. or more in the United States. (Four inches maximum is permitted in the AWS Specifications for Welded Highway and Railway Bridges, although it is considered preferable to use a flange and cover plate rather than a flange thickness of more than 2 in.)

The third bridge in this series is called the Jeanne d' Arc Bridge and is now in the course of erection. It comprises seven box girders each of 650-ft continuous span length. The steel used is the same as for the other two bridges. In all three cases erection is by field welding.

Unfortunately no information was available on the design of these structures, nor on the allowable stresses used. In the instance of the Pont Corneille Bridge it was reported that the cost was $240 per ton (90 fr/kg) as compared to an estimated cost of $272 per ton (103 fr/kg) for a riveted design.

In Germany, a number of bridges were being replaced over the Rhine River in the Düsseldorf-Duisburg area. These were in the nature of sections fabricated from plate by welding and assembled by riveting. The fabricator claimed this procedure to be most economical on the basis that it eliminated joint preparation and careful fit-up of members in assembly. No bridge work was seen in progress in this plant, but the impression was gained that needless forming was being done, as in the flattening of angle members joined to the chords of a crane girder where clearance did not seem a problem. It appeared that welding the heels of these angles directly to the chords, without flattening (as is done in a plant visited in Holland), would have been equally satisfactory and would require less forming.

No welded bridges were seen in Belgium, but in discussion it was reported that the Belgian Highway Department most usually shop welded and field riveted its bridges on the basis of economy determined by experience. However, it was pointed out that this was not a hard and fast rule, some of the bridges being all welded. It was also reported that railway bridges are usually riveted in Belgium.

In the design of welded highway bridges the allowable tensile stress used is 16 kg/mm² (about 22,000 psi) for ordinary steel or 22 to 25 kg/mm² (about 30 to 35,000 psi) for special low-alloy steels. In either case impact is figured as 1.05 times the total dead load plus live load. This factor was formerly 1.5, but has recently been reduced on the basis of experience and tests. The analysis of the two steels used (identified as A37 and A52) were not obtainable. However, it was stated that open-hearth, fully killed steel was specified for important bridge components. Moreover, such steels were purchased on chemistry and mechanical properties including impact at −20° C (−4° F) and an underbead cracking test. Investigation is now under way by the Belgian Highway Department in the use of composite bridges of steel frames and prestressed concrete acting together. Results are not yet available.

Among other bridges discussed were a shop-welded, field-riveted highway arch bridge in Finland, a Vierendel highway truss in Switzerland and a 1200-ton bridge said to be the northernmost welded bridge in Norway. These structures were made of steel produced by a propietary oxygen process.

In Holland, examples of welded highway bridges and repaired railroad bridges were noted. It was stated that these bridges represent the usual practice in that country. Bessemer steel is used for such structures. A typical analysis is 0.15 to 0.20% C and 0.60 to 0.80% Mn. The corresponding mechanical properties are 37 kg/mm² (52,000 psi) tensile strength, 26 kg/mm² (36,000 psi) yield point and 25 to 30% elongation in 2 in.

The steel is usually purchased to mechanical properties alone, but chemistry is reported and considered.

No evidence was seen in Europe of the welding of tier-type buildings. However, it should be remembered that tall, multi-story buildings are the rare exception in Europe. In the fabrication of new mill buildings, power stations and other industrial buildings, there were examples of all-riveted, riveted and welded and all-welded structures. The predominance, including those buildings housing the plants visited, seemed to be of welded fabrication with erection by riveting (see Fig. 17). Similarly the all-riveted building was the exception.

Among the statically loaded structures which were

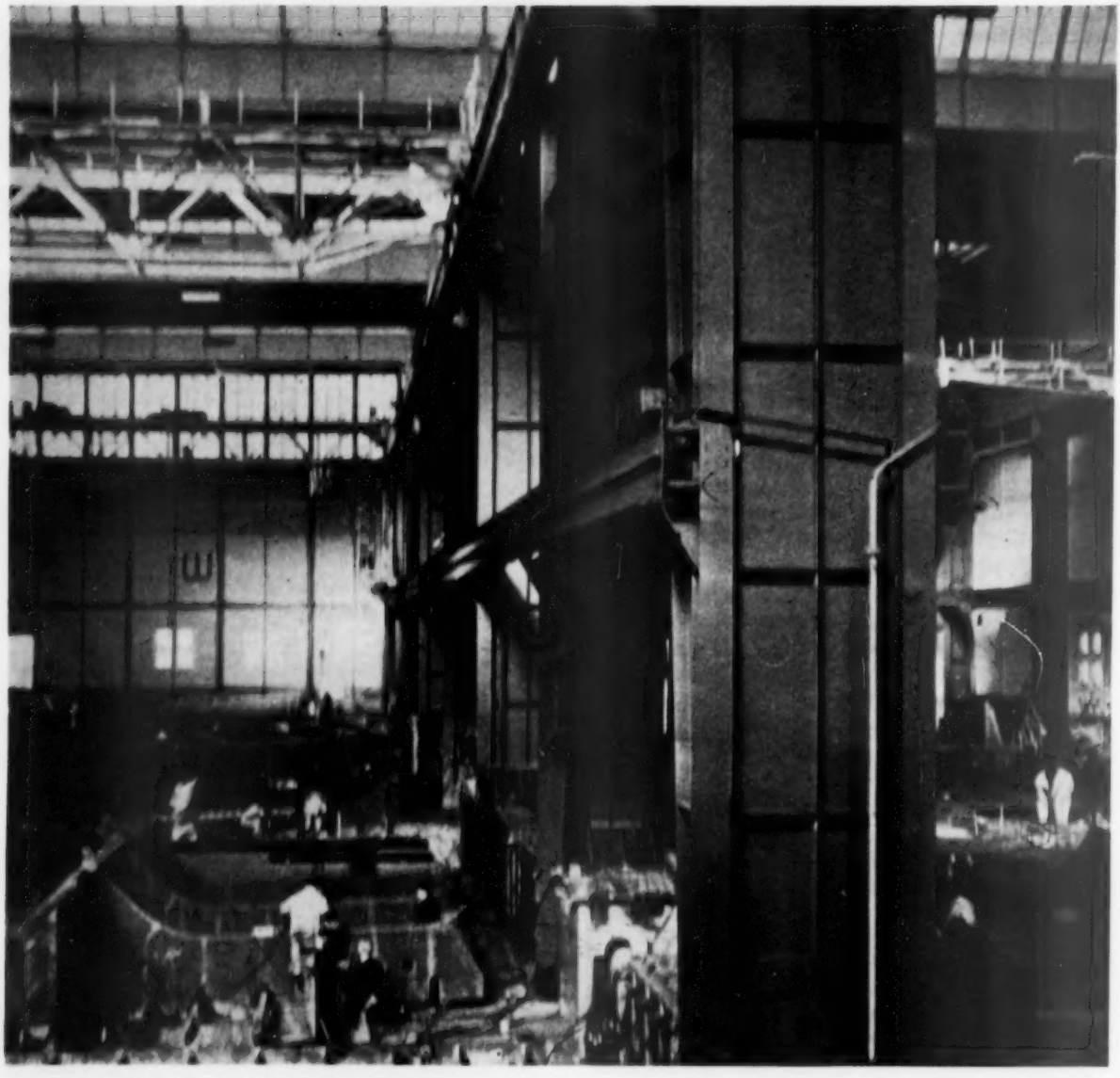


Fig. 17 Welded shop building

noted were bents for mill buildings, transmission towers, and structural frames for power stations. A notable example was seen in Holland. A series of rigid frame bents of 50 meter (164 ft) span were being fabricated. These consisted of welded knees, a beam span of three plates and four column supports. These bents were all welded, with submerged-arc welding used for all long seams.

In the same plant twenty all-welded rigid frame bents, 75 tons each, were being fabricated for a power station in the United States. Here again submerged-arc welding was widely used and the structures were to be both shop and field welded.

Roof trusses were most usually welded in whole or in part. Many light trusses were seen in different plants, composed of angles or small I-beam members which were welded directly to the chord members (see Fig. 18). In one case the angles were flattened at the connection, but this was not usual. In several cases, as in Norway, Germany and Holland, very light roof trusses were riveted. In two cases the explanation offered was that the weight which could be saved in structures of this size by welding could be more than compensated for in the case of riveted fabrication, with less precise fit-up required and elimination of the problem of straightening very light members.

A third type of construction classified here under structural steel, of which a notable example was seen in Germany, is the construction of large cranes and power earth-moving and handling equipment such as shovels, buckets, etc.

Crane runway girders in plants built since World

War II are almost 100% welded (see Fig. 19). The same can be said, possibly to a slightly lesser extent, of the crane spans themselves. In the German plant cranes for shipyards and cargo handling of every size and description are being fabricated from welded plate assemblies. A large 25-ton, 3-legged, Gantry Luffing Crane was being built for use in Egypt. A crane of similar construction was built for a U. S. Navy installation in Florida. It was obvious that emphasis was placed on design in this plant so that maximum use could be made of all steel used and material conserved to the fullest extent. Prototypes are built for each new design and tested using strain gages before the final design is agreed upon and placed in production. Production methods are highly efficient and obviously carefully planned. Some use is made of automatic submerged-arc welding, but for the most part manual welding is used. Assemblies are stress relieved at 550 to 600° C (1050–1100° F).

In general it was obvious that welding practices in this field were up to American standards. Plate edges are prepared most usually by manual oxygen cutting, although machine oxygen cutting is used to some extent. Welds are of good appearance and of proper size and proportion. Details are generally comparable to United States practices, the omission of welding of intermediate stiffeners to tension flanges of girders, for example. Use is made of submerged-arc welding, the extent varying quite widely from one plant to another.

In general the steels used, usually the same for bridges

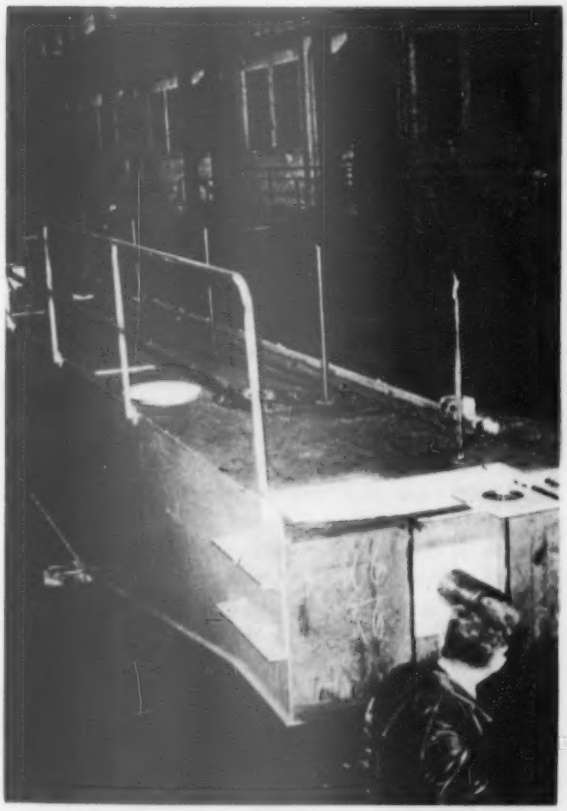


Fig. 19 Crane runway girder

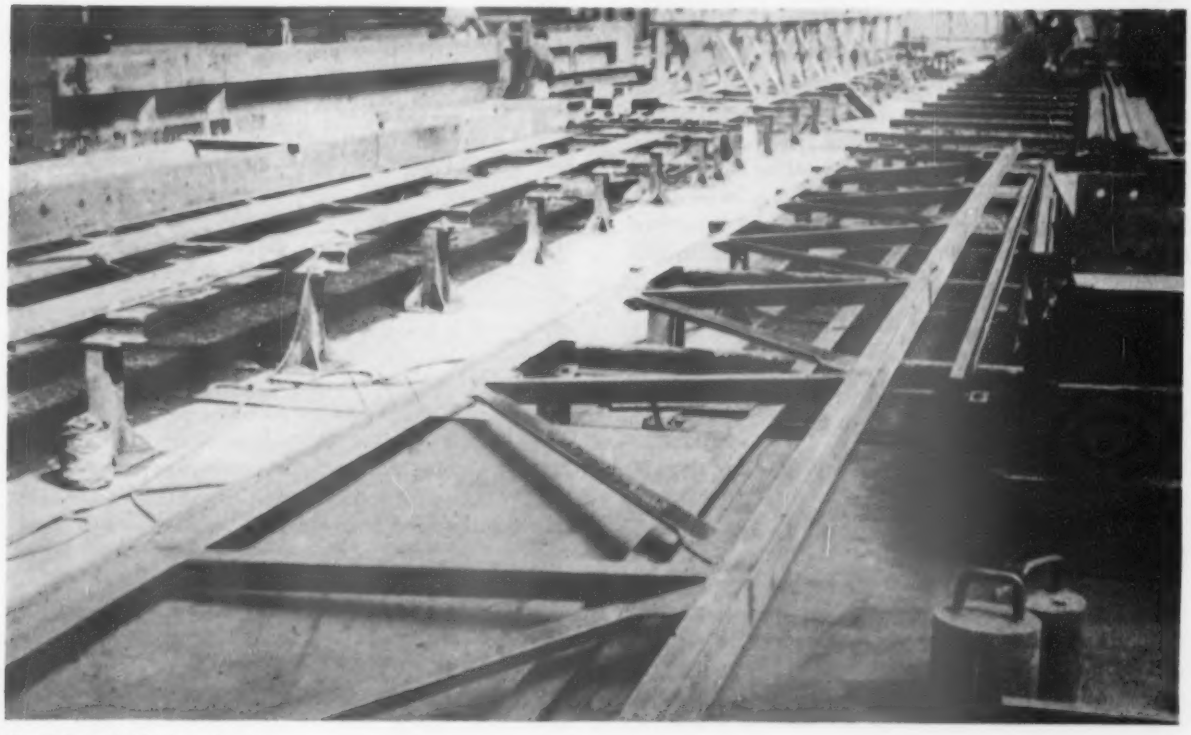


Fig. 18 Welded roof truss

and buildings, are of a lower carbon content than those used in the United States. This fact, together with the practice of using thinner sections, would seem to explain the lack of concern in Europe for what is known in the United States as "weldability." No case was encountered where preheat was used. As in the United States, inspection is almost entirely by visual means.

A distinct preference exists in Europe for the fabrication of members from plates rather than rolled sections. This is possibly due to the relative cost of steel and labor. In Germany, for example, in one plant it was reported as more economical to use up to 80 man-hours of labor to save one ton of steel. (The average German ratio quoted was 1 to 50 and a United States ratio quoted as one ton to 20 man-hours.) This difference between European practice and American practice should not be explained away entirely, however, by these ton to man-hour ratios. The structural fabrication seen in Europe suggests that in any case more care is given to design, and economies are thus effected in labor as well as materials.

In so far as production facilities, these varied widely according to the size and newness of the plant. In some plants the production layouts, welding and handling facilities were especially impressive. There were cases of the opposite as well.

Research in structural welding is being carried on in several European areas. The British Welding Research Association is currently conducting fatigue studies in butt-welded joints. The Association de Industries de Belgique is conducting a program of research on the effect of cyclic loading on structural assemblies of different designs. Structural research on welded designs and connections is also being carried on at the College of Manchester, England.

The foregoing is by no means a complete report of any single visit, nor of all visits. The applications cited have been selected as representative of the overall picture. To us it suggests that welding is becoming the principal means of structural joining in Europe. The need for replacement of equipment destroyed during World War II has contributed largely to this condition.

Pressure Vessels, Tanks and Piping

Welding is being used almost exclusively in the fabrication of pressure vessels, both fired and unfired, and storage tanks including spheres, large liquid containers, both stationary and mobile, pen stocks and cement kilns. Riveting was seen in this field of application on portions of cement kilns being fabricated in Denmark. The extent of welding in this field in Europe is essentially the same as it is in the United States.

The materials used in Europe for pressure vessels, tanks and piping are essentially the same as in the United States. They prefer to use steels with a 0.23% maximum carbon using higher manganese to meet the mechanical properties required. They are using either aluminum or silicon killed basic open-hearth or electric-furnace steel.

It is quite common in Europe for the steel producer to fabricate welded structures of plate produced in his mill. In one steel mill in Germany they are using up to 75% of their own plate output in welded structures. The majority of the steel producers visited fabricate products consisting of pressure vessels, tanks and piping. While not many heavy wall pressure vessels were noted it is our understanding that the mills fabricate most of the pressure vessels used in Germany.

Basic (low hydrogen) type electrodes are used almost entirely in welding pressure vessels, tanks and piping.

The design of pressures vessels, both fired and unfired, is essentially the same as in the United States. One company in France has a new plant where they are building pressure vessels and spheres, primarily for the chemical industry, which are almost exact duplicates of those made by a plant in the United States. In this case, as in many others, these companies are licensed by companies in the United States to fabricate products to the United States design.

In Switzerland one company building penstocks is using reinforcing ribs on branch connections which are not welded to the pipes (see Fig. 20). The reinforcing rib (three pieces) is fitted very accurately to the pipe and welded into a continuous section. This company maintains that this type of reinforcing rib is more effective and less costly than one which is welded to the pipe.

A company in England is making containers for transportation of liquids. They are building some of the largest gasoline trailers for tractor-drawn vehicles used in Europe. The use of welded construction permits design features which would be impractical by other means of fabrication.

Mechanized submerged-arc welding is used very extensively for longitudinal and circumferential joints in pressure vessels and piping. The most common practice is to use manual shielded-metal-arc welding for the backup pass. For plates up to $1^1/_4$ in. thick, single pass submerged arc welding is used. For heavier sections, one pass is made from the inside and one from the outside. In general, plate thicknesses did not exceed 3 in. in the shops visited. A limited amount of mechanized arc welding with continuous coils of covered electrodes is being used in a very few shops. In one case relatively small diameter spheres are being joined entirely by manual welding.

Extensive use is made of machine oxygen cutting of plate to size and for edge preparation using multiple torches. However, edge planers are used more often for the edge preparation of plates, particularly where submerged arc welding is used. Edge preparation and weld appearance are very good and, we believe, equal to what is being done in the United States. Most of the plates are formed into cylinders by rolling. In a few instances, in older plants, heavy presses are being used to progressively form plates into half cylinders.

Quality control in the fabrication of pressure vessels, tanks and piping appears to be excellent with great care taken to control all variables during manufacture.

In general, more use is made of nondestructive testing than would be required by United States codes for similar vessels. Radiography is the most commonly used nondestructive test, as is the case in the United States. In a number of cases magnetic particle inspection as well as sonic tests are being used. Techniques for supersonic testing welded joints are being developed as is a means for locating the depth of defects below the surface. They have not as yet developed standards for interpretation of supersonic tests of welded joints. At present they are using sonic tests as a supplement to the X-ray test for quality control purposes.

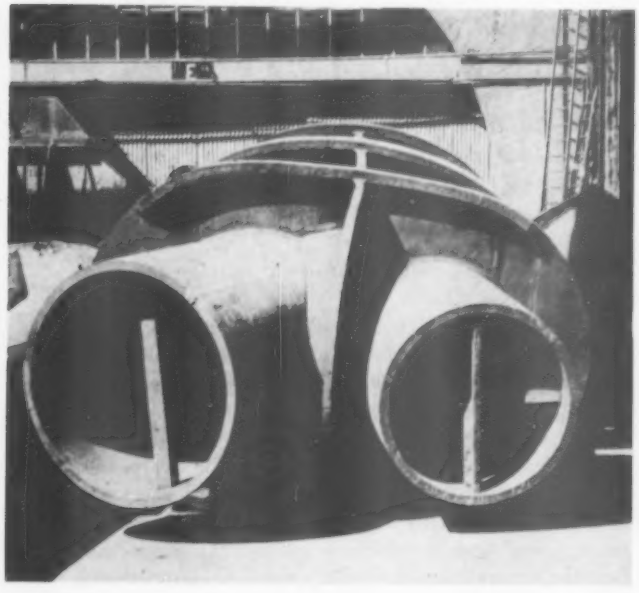
In general, the work and welding head positioners for mechanized welding being used are very good. In this respect, their equipment and facilities are very similar to those used in the same industries in the United States. The extent to which they use handling facilities appears to be purely a question of economics.

Light Alloys

A limited number of the plants visited in Europe are engaged in the welding of light alloys. Except from an experimental standpoint, no welding of magnesium-base alloys was seen. In the welding of aluminum, inert-gas metal-arc welding, using a tungsten electrode is generally used. One application in England uses the consumable electrode method for welding aluminum. Argon is used exclusively; helium is not available in Europe. In two plants, use is made of flash welding in the fabrication of aluminum window frames. In other applications, spot or seam welding is used. From the information that was obtained, the aluminum alloy used in Europe generally contains 3 to 4% magnesium. In some of the nonconsumable method applications, the aluminum filler metal is a 5% silicon alloy.

A French plant is making welded aluminum automobile bodies. The bodies and some parts of the automobile are produced using inert-gas metal-arc welding, nonconsumable electrode method and spot welding with portable guns. In England, aluminum structures with a thickness of approximately $^3/_8$ in. are welded using the consumable electrode method. In Norway, aluminum life boats, life rafts, ladders and transport packs are welded using the nonconsumable electrode method. In Denmark, the same method was seen used in an experimental setup. In Belgium, rather extensive use is made of the nonconsumable electrode method for welding bulkheads and roof sections of railroad cars. Spot welding is also used in this application. In Switzerland, sheet aluminum is used in combination with extruded shapes, using the nonconsumable electrode method of inert-gas metal-arc welding.

Fig. 20 Penstock assembly



Use of light alloys in Europe, as far as this Mission observed, is somewhat less than that in the United States. Almost all the welding of aluminum alloys is carried out using the nonconsumable electrode method. No heavy aluminum sections were seen. The use of the consumable electrode method was observed for only one application. It is felt that the companies which were visited on this tour might not be entirely representative of the amount of welding of aluminum which is carried out in Europe.

Conclusions

The foregoing report necessarily reflects only what we observed and only the information available to us in the plants visited during the tour. While variations from the practices cited could surely be found in other European companies, we feel that they are representative of over-all European welding practices.

The American members of Mission 250 have been keenly interested in obtaining technical details in so far as possible. At the same time we have tried to form basic impressions from what we have seen which would make possible a comparison of European and American welding practices. These may be briefly summarized as follows.

We believe that European industry is technically advanced to the same extent as American industry. This is a fact which may not be sufficiently appreciated in the United States. Moreover, from the standpoint of productivity it is clear that more man power and less mechanization is used in Europe than in corresponding operations in the United States. We believe this difference is based on economic considerations and the relative costs of labor and materials rather than a lack of familiarity with mechanization methods. European industry is surprisingly well aware of overseas developments in this as in other industrial aspects. We are convinced that if economic considerations or conditions in the world market would require it, European industry could readily increase its productivity accordingly.

It remains for American industry to decide whether contact with European activities is advantageous for a continuing exchange of ideas and developments and, if so, the nature and extent of participation in organizations such as the International Institute of Welding and the International Standards Organization.

Fig. 1 Two welders working simultaneously to complete the weld in high-pressure piping

BACKING RING ELIMINATION PERMITS ULTRASONIC TESTING AND AVOIDS CRACKING AT PIPING WELDS

Pipe welds made without backing rings can be examined by relatively low cost ultrasonic inspection. Also, this technique excludes stress concentration at root of weld and the related hazard of cracking

BY W. A. POLLOCK

Introduction

Elimination of backing rings in all of the pipe welds at the Oak Creek Power Plant excludes the hazard of a ring being loosened by vibration or other causes and damaging turbine blading. An even greater merit, when applied to alloys such as 2¼% chrome 1% molybdenum (P-22), which is more notch-sensitive than carbon steel, is the exclusion of the points of stress concentration at the root of the weld and the resultant hazard of cracking.

That high-quality root beads could be made in the absence of backing-up gas, by using a tungsten electrode with an inert shielding gas, was found practical after development of proper end preparation.

A very important by-product of the effort spent in the backing ring elimination was the discovery that relatively low-cost ultrasonic inspection of the welds was entirely practical and could replace the more expensive and less satisfactory gamma-ray inspection. Periodic reinspections are readily made to learn whether

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the minor indications shown by the sonic test are insignificant, and whether perfect reliability is retained.

A tubular preheater element development permitted time-clock starting and indefinite holding of preheat temperature during night and week-end periods permitted the scheduling of welders and associated crafts on more desirable day shifts and eliminated necessity for round-the-clock welding of the P-22 alloy.

Description of the Welding Procedure

Adoption of the practice of welding without backing rings as standard practice with the first Oak Creek unit was the first basic change in our company's high-pressure pipe-welding procedure since pipe-joint welding was adopted in the mid 1930's.

Figures 2 and 3 show the typical welding-end detail. Special precautions proved necessary in practice and incorporated in the drawing are the infallible protection of the pipe ends against damage during shipment, and the unusually close tolerances which experience with three units and approximately 1000 welds has proved practical.

Perfect matching of the internal diameters, readily obtained by slight internal turning at the fabricator's shop, is required to eliminate "stress raisers." To minimize the amount of turning, the fabricator preselects the pipes which are to be used for each pipe connection. Accurate alignment of matching pipe ends as well as a sufficient length of small cross section at the pipe end are required to prevent cracking when the pipes are joined by fusing the ends without the addition of filler metal.

Early experiences with this welding procedure were discouraging. The first designs of end protection were not satisfactory and many pipe ends needed repair prior to aligning. The ends on the early welds were not truly matching and there was considerable difficulty in fitting. Now that the ends are properly prepared there is very little need to do any field fitting work. Actually, there is no reason why precision fits cannot be supplied for pipe ends as well as for machine parts. It is only a matter of obtaining complete cooperation of the fabricator.

A 0.004-in. clearance is the usual maximum opening

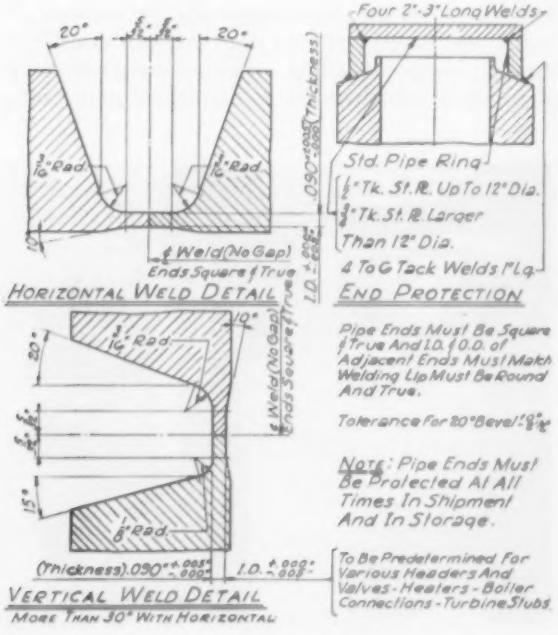
20°
3/16" Rad.
Weld (No Gap)
Ends Square & True
HORIZONTAL WELD DETAIL
Four 2"-3" Long Welds
Std. Pipe Ring
1/2" Tk. St. R. Up To 12" Dia.
3/4" Tk. St. R. Larger Than 12" Dia.
4 To 6 Tack Welds 1" Lg.
END PROTECTION
Pipe Ends Must Be Square & True And I.D. & O.D. of Adjacent Ends Must Match Welding Lip Must Be Round And True.
Tolerance For 20° Bevel ±2°
Note: Pipe Ends Must Be Protected At All Times In Shipment And In Storage.
15°
1/2" Rad.
(Thickness) .090" +.005" -.000"
I.D. ±.000" -.005"
To Be Predetermined For Various Headers And Valves - Heaters - Boiler Connections - Turbine Stubs
VERTICAL WELD DETAIL
MORE THAN 30° WITH HORIZONTAL

Fig. 2 High-pressure welding end detail—typical

Fig. 3 End protection shown on a 15 3/4 in. OD pipe as delivered to plant

Fig. 4 Clamps used to maintain alignment instead of tack welding

Fig. 5 Aluminum flux being painted on pipe ends after alignment. Absence of gap is important for crack elimination

Fig. 6 Tubular preheater elements are easily installed and are unusually rugged and reliable

allowed between pipe ends as they are lined up. This maximum clearance is realized by minor filing of the "lips" in case minor fitting is a necessity.

The fabricators are requested to avoid painting 3 ft of each pipe end because this paint melts and contaminates the weld. As shown in Fig. 4, the pipe ends are thoroughly cleaned and dried and then are held in position by strong bolted clamps instead of tack welds while preheater elements are attached to the pipes to be heated. The cleaning contributed to noncracking of root weld. An aluminum flux is applied as soon as alignment is complete and clamps are tightened, as illustrated by Fig. 5.

Tubular preheater elements, discussed later in this paper, are clamped to the pipes, as shown in Fig. 6. Temperature is maintained at 600° F during the entire welding process. Wisconsin Electric Power Co. specifications permit cooling after half of the wall thickness has been welded. This is done when a weekend or holiday interrupts continuous working.

The root pass, applied next, is shown in Fig. 7. This is followed by two passes with $^{3}/_{32}$-in. coated electrodes and the remaining passes to completion by using $^{1}/_{8}$-in. and $^{5}/_{32}$-in. electrodes, illustrated in lead photo, i.e., Fig. 1. Slag and pinhole removal is by wire brush, rotary files and grinding wheels, as shown in Fig. 8.

Next, the weld is stress relieved at 1350° F by induction heating using 750,000-cm flexible cable (Fig. 9), and finally the completed weld is checked carefully with a shear wave ultrasonic test apparatus, pictured in Fig. 10. The pipe is allowed to cool between completion of weld and stress relief.

Examination of the root-pass surface within the pipe has proved many times that it is favorably smooth and free of scale. It may be curved slightly inwardly or outwardly, but it has no stress raisers. The outward curving occurs only when tight fitting is not done in aligning. Practically all welders can qualify for consistently smooth interior surface after receiving proper training.

Some Early Considerations of Backing Ring Elimination

Failure of a welded joint in the steam line of the Springdale Station of the West Penn Power Co. in January 1943, as a result of graphitization, focused the attention of the power industry on the need for extreme care in the selection, design, fabrication and erection of high-pressure, high-temperature piping. Millions of dollars have been spent, consequently, for research, for repair, and for replacement of piping in which graphitization occurred due to operation temperatures in excess of those desirable for 0.5% molybdenum piping.

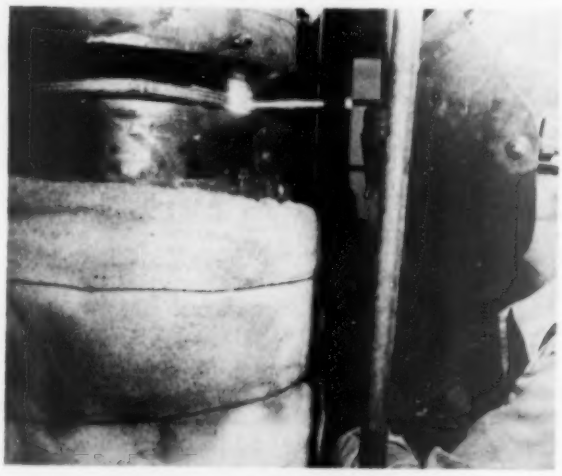

Fig. 7 Inert-gas arc weld used for root bead

R. W. Emerson[1] published a picture of a welded joint, exhibiting intergranular graphitization at the extremity of weld heat-affected base metal. That photograph, reproduced in several of the subsequent articles on the subject[2,3], and a photograph in another article[4] were, in part, responsible for investigations by our company, not only into graphitization, but also into the method whereby backing rings could be eliminated when making welds in high-pressure piping and thus eliminate the stress raiser.

The photograph in Emerson's paper shows a weld joining two pipes and a recessed backing ring on the inside of the pipe. The backing ring is not tightly adherent to the inside of the pipe, but a gap equal to the thickness of the backing ring exists. The ring has apparently been caused to warp away from the inside pipe wall by the welding and stress-relieving processes. Cracks are evident at the root of the weld joining the backing ring and the pipe metal.

That these cracks exist is not unexpected because of the notch at this juncture. In operation, at each alternate heating and cooling, the backing ring, due to its relatively lesser thickness, heats up and cools down more rapidly than the adjacent pipe and high stressing of the notch results.

The void between the pipe and the backing ring occurs even though the rings are tailor-made in the field. The void affords an excellent location for corrosion to start, especially in boiler feed lines, due to oxygen. If acid cleaning is practiced, it is almost impossible to neutralize all of the acid, and corrosion takes place under the ring.

Potential Accidents Initiating with Backing Rings

Several unfavorable experiences with backing rings at the Port Washington power plant of our company hastened the investigations which led to the ultimate elimination of backing rings. A backing ring in an 18-in. reheater outlet line was found loose and was removed from the pipe without the aid of any kind of a tool. This backing ring had been installed by a piping fabricator when he was welding a short length of pipe to a gate valve. Welders had not fused the ring and the pipe together and an inspection revealed that slag from the welding electrode had filled the space between the ring and the pipe. Had not this loose ring been found it might ultimately have worked its way into the turbine blading because that ring was not recessed and there was no strainer between it and the turbine.

On another occasion, a section of carbon-molybdenum pipe was removed after several years' service to install steam dump valves in the reheater lines between the outlet from the reheater and the inlet to the turbine. The welds in the removed section were examined for graphitization and some separations between the backing ring and pipe were found.

Internal inspection of boiler feed lines at the boiler feed pump discharge flanges and through check valves revealed that corrosion under the backing rings has occurred due to oxygen in the feedwater at start-up and during very low loads, as well as due to acid attack from acid introduced when cleaning the water side of extraction heaters. In some cases the backing rings

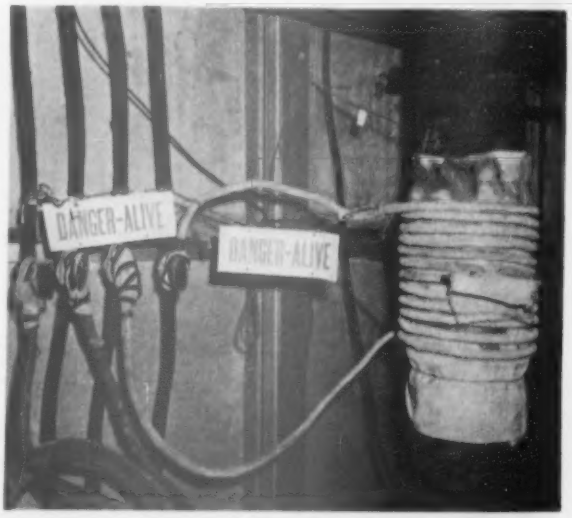

Fig. 9 Stress relieving by induction heating follows weld completion. Cables at left with connectors at each elevation provide stress-reliever supply with minimum cable handling. A second weld is being stress relieved on right

Fig. 8 A rotary file is used to remove slag and pinholes

are more than half gone, even though there is only minor attack on the inside pipe wall. The turbulence they cause is destructive of natural protective coatings.

A June 15, 1955, report of an inspection of boiler feed piping and check valves from Port Washington power plant stated in part as follows:

No. 7 Boiler Feed Pump

The valve body was clean and there was no evidence of new erosion.

Piping on the upstream side to the bend was in good condition and clean to touch. The weld joint, where valve body and piping meet, was made in November of

1954 after piping was removed to permit weld repair of a valve body leak. No backing ring was used. Inspection was by sight only, as writer could not get arm through valve body and into pipe in that direction.

Piping on the downstream side of the check valve was also in good condition, smooth and clean, to the discharge valve. The backing ring at the weld where the valve body and pipe are joined has been eroded away. A $^1/_8$-in.-deep groove exists around the entire circumference.

No. 9 Boiler Feed Pump

The valve body was clean and showed no new signs of erosion.

Piping on the upstream side of the valve to the first bend was clean and in good condition. The backing ring at the weld where piping joins the valve body has been eroded away. A groove $^1/_8$ in. deep in relation to pipe surface, and $^1/_4$ in. deep in relation to valve body diameter exists at this point.

Fig. 10 Ultrasonic inspection. The engineer, using an angle crystal, probes for indications of flaws. The standard specimens for calibrating the instrument are at the lower left

On the downstream side of the valve, to the first bend, piping also appeared to be clean and in good condition. The backing ring at the weld where piping joins the valve body showed signs of erosion. About 90 deg of the ring circumference at the top of the pipe is eroded considerably, and similar erosion has occurred at the 7 o'clock position, looking downstream. Some metal loss from the valve body just ahead of the backing ring was noted at the latter location (7 o'clock).

That backing rings were entirely eroded away in piping operating since October 1948 is alarming. Whether the rings waste away or break off in larger pieces cannot be predicted. If the latter occurs, serious troubles may be expected. The adjacent pipe was not similarly eroded, and one is caused to wonder about the condition of all of the rest of the backing rings which cannot be inspected. One important change in operation to arrest further corrosion has been substitution of demineralizers for evaporators with the benefit of preventing carbon dioxide from entering the pre-boiler cycle.

Early Developmental Work Initiated

Adoption of 1000° F steam temperature at Oak Creek resulted in selection of the 2¼% chrome 1% molybdenum alloy.

Search of the literature at that date did not reveal that anyone had developed a satisfactory method of welding high-pressure alloy pipe in the absence of backing rings although as early as 1947 an article by Eric Seabloom[5] discussed alloy pipe welding and showed a welding groove without a backing ring.

Conferences were held with Messrs. John Chyle and R. Keller of A. O. Smith Corp., L. J. Larson of Allis-Chalmers Co., F. Boicourt and V. Rowland of Travelers Insurance Co.; and many valuable suggestions were received. Many tests were conducted using an acetylene torch with and without filler rods, and various coated welding rod sizes and weld-end details were tried in an attempt to weld without backing rings. The 2¼% chrome 1% molybdenum alloy pipe which was to be used at Oak Creek power plant was used in these trials. Finally the inert gas welding torch with nonconsumable electrode was adopted. Backing-up gas was found unnecessary with the design of welding groove adopted, as shown in Fig. 2.

The practice of welding all high-pressure steam and water piping without backing rings became standard company practice with the first Oak Creek unit. The insurance company afforded unqualified approval after helping develop and test the procedure.

To join the pipe ends properly, the experience with Oak Creek 1 showed that it was necessary to protect the ends adequately in shipping and erecting. The fabricators have cooperated and furnished the matching ends to the internal diameter tolerance of + 0.000, −0.005 in. The close fitting of the internal diameters and complete penetration of the inert arc root weld have completely eliminated the stress raisers and provided the smooth inside surfaces so necessary to properly inspect with ultrasonic test methods. The $^{5}/_{32}$-in. straight section of the pipe end is approximately $^{1}/_{16}$ in. more than actually needed, but this excess has been found desirable to allow some filing for fitting when bends are not exactly as specified.

Ultrasonic Test Method Adopted

Ultrasonic testing was first used by the writer's company to inspect the pipe ends for imperfections. This was reported in a discussion of a paper in 1951 by the writer.[6] One crack several inches long and $^{1}/_{8}$ in. deep, which was found in an elbow next to a reheater header on a Port Washington unit, was repaired, preventing a possible forced outage. It was natural that, after the internal surface of the pipe was smooth because the backing rings were eliminated, ultrasonic testing was considered as a pipe weld inspection method. A previous trial of the ultrasonic method of weld inspection with backing rings at Port Washington had proved unsuccessful because of the interference reflection of the backing ring.

Specimens with known defects such as slag inclusions, lack of penetration to the root and cold shuts were put deliberately in a test weld. All were located reliably by the service engineer, in qualifying the ultrasonic method of testing. It was concluded that ultrasonic inspection of welds of the type tested was "possible with clear and consistent results."[7]

In service, minor defects were found but in all cases they were less than that allowed by the ASME code for piping defects when using gamma-ray testing. After one year of operation these welds were reinspected, and the same defects were located and found to be of the same magnitude as they were originally.

An engineer of one of the large insurance companies observed the tests, and the qualification test was arranged with his assistance. His company has given its approval to this test procedure when the test is administered according to the established procedure.

This use of ultrasonic inspection of welds was not new. Its use was predicted in 1950 by W. B. Bunn and W. J. Mitchell.[8] Their report stated in part, under the heading "Weld Inspection": "There is no question that ultrasonics will also find its use in weld inspection. Equipment is quite portable and reasonably fast. However, it has certain basic deficiencies, among which are: (1) lack of a permanent record, (2) greater dependence on skill and integrity of the operator and (3) difficulty in establishing a standard of acceptance that will detect minor but dangerous discontinuities in the root areas of the weld."

We believe that the taking of pictures of the screen of the instrument when indications are found by ultrasonic testing will provide a permanent record. This, accompanied by a careful log of test observations, will provide as good a record as the steel forging manufacturers furnish turbine manufacturers for their large turbine and generator forgings. Then, too, a recheck is made easily by simply removing the pipe insulation during an outage, and repeating the initial tests. The complete weld can be reinspected at such times.

There is no substitute for a skillful and dependable

ultrasonics operator. Our company is so convinced of this that it prefers to employ a commercial inspection service in order to obtain the best in experience and test technique.

The elimination of the backing ring has reduced the problem of obtaining a good ultrasonic indication of the condition at the root of the weld. Further, it has been found that if the pipe walls do not line up perfectly, by examining the weld from both sides, it is possible to evaluate accurately the amount of difference in the internal diameters. If examination from one side of the weld gives an indication and from the other side gives none, one can safely conclude that there has been 100% penetration to the inside diameter of the larger pipe diameter. If there is an indication from both sides, the lesser of the two indications can be taken as the amount of lack of penetration.

A New Standard for Ultrasonic Inspection Is Proposed

There is much to be said for establishing standards of inspection. Up to the present time it has been usual practice to make up a test piece of pipe to provide curvature and wall thickness exactly like that to be tested and to simulate a defect of 1% by making a small chisel mark in the surface. This has given a far greater sensitivity than is apparently desirable, and due to this high sensitivity the inspection is slowed down somewhat. It is believed that the standard should be established by drilling a hole into the test pipe with a flat bottom drill with a diameter 2 or 3% of the wall thickness. This hole should be drilled at the same angle as that at which the ultrasonic crystal transmits its beam so the beam will strike the bottom of the hole squarely.

Advantages of Ultrasonic Testing

The several advantages of ultrasonic inspection are: (1) rapid; (2) relatively inexpensive when compared to X-ray or gamma-ray; (3) the equipment is very portable, especially now that a smaller one-wave tester has been developed; (4) retests may be made of areas where minor defects are noted, these retests being on a periodic basis to learn whether the defects need removal or repair; (5) at these reinspections the entire weld is reexamined for soundness; (6) these reinspections do not require drilling a hole for the radioactive cobalt insertion and the subsequent rewelding and stress relieving of the repair; (7) an independent referee is obtained when the inspection is contracted for through a company providing this service.

Tubular Preheater Element Development

Preheating the 2¼% chrome 1% molybdenum piping during the several shifts of welding presented somewhat of a problem.

Most authorities agree that it is desirable to maintain preheat temperature through at least half of a weld. Many contend that the weld should not cool down until the weld is completed and some recommend that the stress relieving follow welding immediately. Because no adverse effects could be found in tests when half of the weld was completed before allowing cooling, that procedure was adopted.

Preheating by resistance elements is favored over induction coils because of the less expensive equipment requirements. Then, too, when induction coils are used, it is necessary to shut off the current during welding. The only resistance elements offered by the manufacturers for this service were 250-watt strip heaters which were strung together in No. 10 solid wire to produce adequate heating capacity. These heaters were not rugged and failed due to short circuits, burnouts and mechanical damage. The delays caused by failures were time consuming and the man-hours lost due to the delays were expensive.

A tubular preheater element of 2100 watts bent in a sinusoidal shape, designed and made up for trial, proved satisfactory and was adopted for Oak Creek 2. Several advantages have accrued, affording savings of over $16,000 for the 350 welds of each unit.

Since the heaters are flexible enough to form to the various pipe diameters, only one size is needed. No cleaning or preparation is required after the heaters have been used in order to prepare them for the next weld. The fitters can fasten them to the pipe with a single stainless steel strap which is tightened with a bonding tool. Welding is conducted on a day schedule and heat is maintained over week ends without anyone in attendance. The heat is turned on by time clock during the night prior to start of a weld and is up to the desired temperature at the beginning of the shift.

Information on design details and procurement of these heaters will be furnished upon request.

Acknowledgment

In addition to valued assistance of the representatives from Travelers Insurance Co., A. O. Smith Corp. and Allis-Chalmers Manufacturing Co., it is a pleasure to acknowledge encouragement of Messrs. M. K. Drewry and O. J. Stallkamp in preparing this paper as well as their counsel in development of the welding program. Messrs. Walter Goetz, Martin Goetz, Carl Thiele, C. Bergquist, W. J. Hellen and L. J. Niebler have been generous with assistance in developing and carrying out the details outlined herein. Messrs. N. Marinin and P. Markiewicz rendered valuable assistance in developing the welding technique. In addition to the above fellow employees of Wisconsin Electric Power Co., Mr. Sheldon Leonard of Sperry Products, Inc., has also assisted materially in making this program successful.

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RADIOGRAPHY IN THE JUNGLES OF SUMATRA

BY WALTER W. OFFNER

Construction and weld inspection of large oil storage tanks at an ocean fueling station in Sumatra

Introduction

To our knowledge, the first time that radiographic inspection of field welded seams was done in Indonesia occurred in October 1954. Some large oil storage tanks were being erected in the swamps on the Straits of Malacca in Sumatra. These 160,000-barrel tanks were part of an ocean fueling station. The crude oil came from the oil fields in the interior and was pumped into small—25,000-barrel—river tankers, which transported it down the Siak River where it was unloaded in to a battery of eight large storage tanks located at a small deep-sea harbor. These tanks were erected by an American fabricator with American welders (see Fig. 1).

Walter W. Offner is associated with X-Ray Engineering Company, Mill Valley, Calif.

To be presented at AWS 1955 National Fall Meeting in Philadelphia, Pa., Oct. 17–21, 1955.

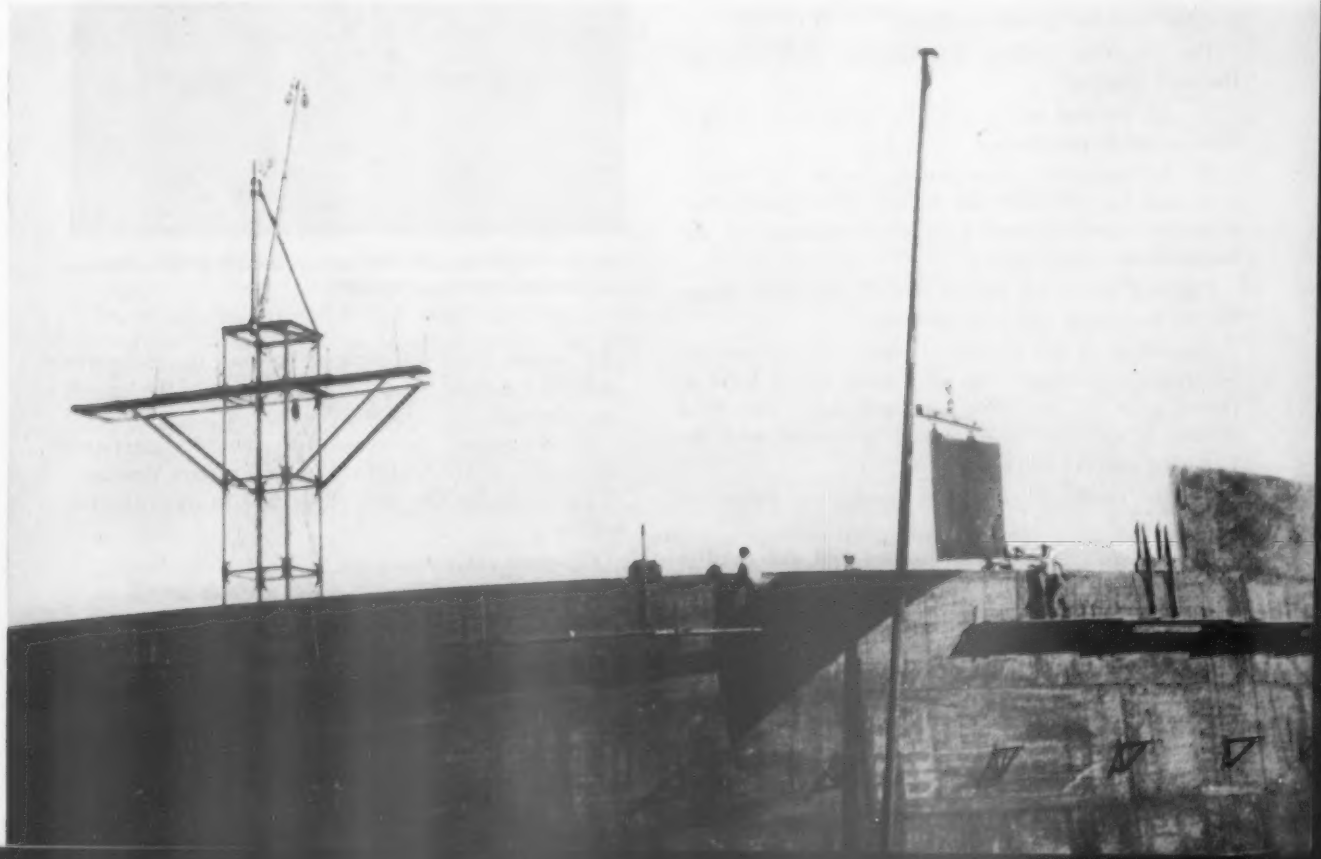
Welding and Inspection Specifications

In the absence of adequate API specifications for tank erection at that time, the owners drew up their own welding and inspection specifications as follows:

1. A dependable welding job shall be insured by maintaining close supervision and close inspection of welding as it progresses. A company-designated welding inspector will check the welding as it progresses and examine all welding after completion. All defects shall be removed.

2. Welding of all shell plates 13 mm ($^1/_2$ in.) and over shall be subject to radiographic examination unless specifically waived by the company, and this radiographic examination shall be carried out at the company's expense.

Fig. 1 Tank erection in Sumatra



3. Radiographic examination of plates 13 mm and over will normally only be waived when the scope of the tank erection does not warrant the expense of radiographic equipment. When radiographic examination is waived, inspection shall be by trepanning under the provisions of API-12C.

4. The minimum extent of radiographic examination of the vertical welds of plates 13 mm and over shall be as follows:

All weld intersections, with the long axis of the radiographic film along the axis of the vertical weld. A minimum film length of 31 cm (12 in.) shall be used. At least one radiograph of the welding of each welder per day.

All welds of doubtful appearance.

100% examination of any vertical welds found defective in the above.

100% of any repair welds.

5. Radiographic examination of the girth welds will normally not be required and trepan examination as required under the inspection section of API-12C will be carried out except that radiographic examination of all trepan hole repair welds in plates 13 mm and over shall be carried out unless specifically waived.

6. Inspection of welding in plates under 13 mm shall be by trepan examination except that 10% random radiographic examination of the vertical welds can be substituted for trepan examination.

7. The radiograph shall meet the ASME 1950 Unfired Pressure Vessel Code except the penetration requirements will not apply to girth welds. All repairs shall be at the contractor's expense.

8. Qualification of welders for welds to be radiographed shall be by radiographing.

The following welding specifications were used for the shell welding:

1. All vertical joints shall be double-butt welded with complete penetration and fusion.

2. All horizontal joints shall be double-butt welded and shall have a minimum of two-thirds penetration with the unwelded area located substantially at the center of the thinner plate.

Figure 2 shows the details of shell butt-joint design for the horizontal and vertical seams.

Inspection of the horizontal seams was carried out by trepanning except that all welded trepan holes in plates over 3/4 in. were radiographed. The weld quality of the vertical seam had to comply with the following points to be acceptable:

1. No cracks or areas of incomplete fusion or penetration.

2. No elongated slag inclusions and gas cavities in excess of 1/4 in. when T is less than 3/4 in. and 1/3T when T is 3/4-in. and over. T is the plate thickness being welded.

3. No successive slag and gas inclusions in line having an aggregate length greater than T in a length of

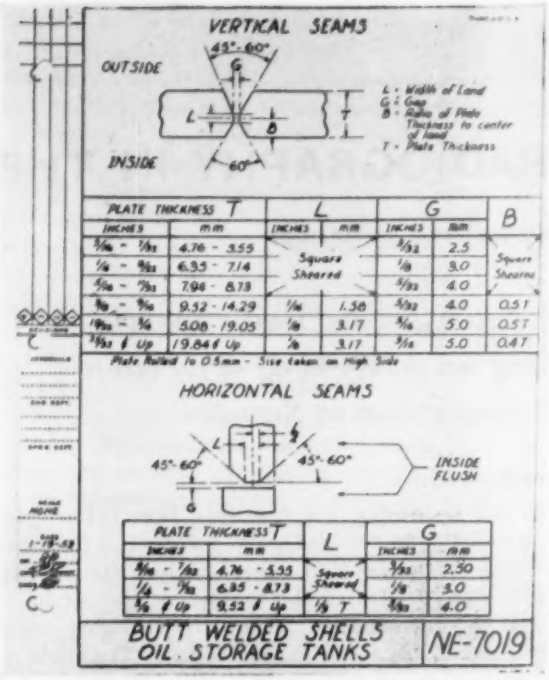


Fig. 2 Specifications of shells

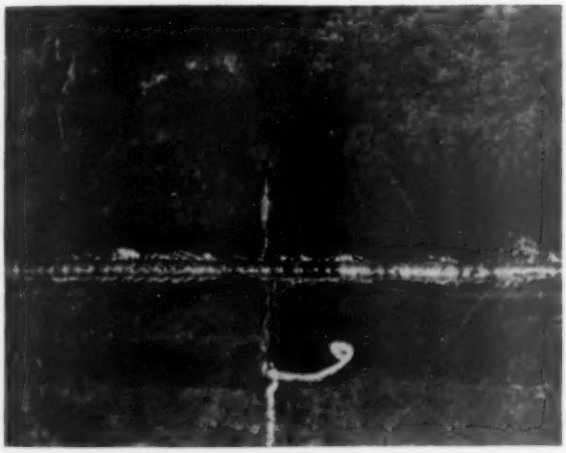


Fig. 3 Weldment cut with carbon arc-air process reveals slag inclusions and gas porosity

12T, except when the distance between the successive inclusions exceeds 6L, L being the length of the longest imperfection.

4. No porosity in excess of the porosity standards of the API-ASME Code for Unfired Pressure Vessels.

The plate for the tank shells had to meet the following:

Chemical composition

Carbon, max %	0.30
Manganese, %	0.60–0.90
Phosphorus, max %	0.04
Sulfur, max %	0.05
Silicon, %	0.15–0.30

Tensile properties	
Tensile strength, psi	60,000–72,000
Yield point, min psi	33,000
Elongation in 8 in., min %	21

The welding rod for shell joint welding had to be equivalent to: Classification E6010.

Back chipping and weld repairs were done by the carbon arc-air process.

These, in short, were the requirements for the erection of the 160,000-barrel tanks as far as this paper is concerned.

Actual Tank Construction

The actual construction deviated somewhat from these specifications. Construction was started without radiographic inspection facilities. Low hydrogen electrodes $^1/_8$ and $^3/_{16}$ in., manufactured in Holland, were used.

The first indication of trouble is shown in Fig. 3. This is a photograph of a weld taken after the back-chipping operation at the beginning of the job. Considerable gas porosity and slag inclusion in the root of the weldment can be noted. Also, areas of poor penetration were occasionally observed by the company's resident welding inspector. These unsatisfactory findings were brought to the attention of the Indonesian representative of the European electrode manufacturer in Djakarta who forwarded the following reasons for the poor performance of the low-hydrogen electrode used: (1) welder had no experience with rod; (2) incorrect welding current; (3) arc too long; (4) incorrect welding speed; (5) wrong position of rod; (6) moisture in coating; (7) incorrect preparation of joints; (8) incorrect size rod; (9) chemical composition of base metal.

After investigating all nine points the difficulties were narrowed down to four: (*a*) welders' inexperience with rod; (*b*) incorrect welding speed; (*c*) moisture in coating; (*d*) incorrect size rod.

Anyone with welding experience outside the USA knows that the American welder is very reluctant to use foreign-produced welding electrodes. The very idea gives him the jitters. I would like to cite a previous experience I had in the Middle East. A group of American welders—all of them good craftsmen—were prevailed upon to use a British-made American brand electrode. Most of the welds radiographed were very poor. The welding engineer was puzzled because the electrode was practically the same as the American-made electrode and he himself could make a good weld without difficulty. He was desperate until he had the brilliant idea of packing the British rod in American rod boxes. He had no weld trouble the next day.

Point (*b*) was easily explained. The high welding speed was directly related to the welders' pay: more footage—more dollars. Point (*c*)—"moisture in the coating"—was very correct. The humidity on the job site was around 80%, the temperature was from 80–90° with occasional heavy showers. The rod, when it wasn't left open in the welding shack, was stored in an entirely inadequate drying box. Point (*d*)—"incorrect rod size"—was like point (*b*), related to the welders' pay: large rod—more footage—more pay.

Getting There

This was the situation when the services of the organization with which the author is connected were requested. We received a long distance call to ship an engineer and inspection equipment immediately to Singapore. We had the engineer available but all our equipment was tied up on other jobs and it was rather difficult to immediately procure an X-ray machine in the USA. It was also impossible on such short notice to get an authorization from the Atomic Energy Commission to ship isotopes to Indonesia. The first tank was 50% completed and therefore it was essential to start radiographing immediately in order to keep weld repairs to a minimum. We phoned an X-ray equipment manufacturer in Germany and had him airship a small portable X-ray machine to Singapore. All other accessories such as processing tanks, cassettes, etc., were air-freighted from San Francisco. X-ray films and chemicals were obtained in Singapore and brought to the job site on the Straits of Malacca by company boat. It took just about ten days to get everything going, including passport and the necessary visas. The author left San Francisco by Canadian Pacific Airline for Sydney, Australia. From there he flew via Darwin to Djakarata in Java. A small freight plane then took him and his equipment to Central Sumatra; then by motor launch he was brought to the company's base camp where he stayed for several hours to get rested and cleaned up. Then a "hot-rod" Indonesian took him for a three-hour ride in a jeep through the jungle to a small river harbor. From there a river tanker took him on an eight-hour ride down the river to the Straits of Malacca—the author's destination. All in all, it took almost six days to get on the project site.

Setting Up the X-Ray Laboratory

The first thing on arrival was to test the machine and check all materials. The next step was to build a darkroom and get light and water connections. It was then that we got our first surprise. We were informed that there were no wells and everybody was dependent on rain water. That, of course, eliminated the possibility of running water but, since there was plenty of rain, we did the next best thing. When building the darkroom, the palm fronds which were used to make the darkroom roof were sloped so that the rain would drain into a 50 gal barrel from which the water was piped to the processing tanks inside the darkroom. Then we let the natives do a rain dance and pray for rain, of which we got plenty. The author had only a few 5-gal chemical solution changes and had to be very careful not to spoil any and therefore, cleanliness in the darkroom was absolutely essential. The maximum through-put was 620 $4^1/_2$ x 17-in. films.

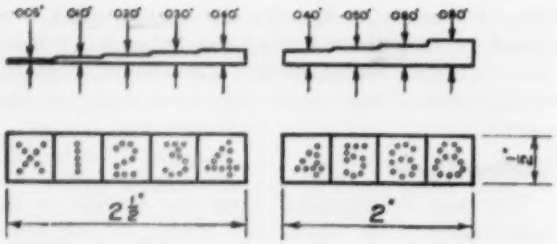


Fig. 4 Penetrameter as per code of Standard Association of Australia

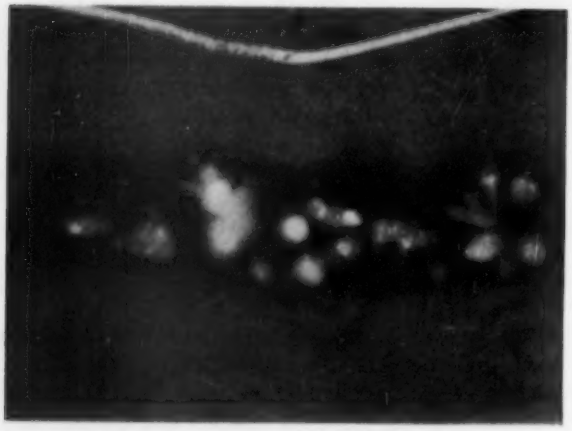


Fig. 5 Gas porosity in weld made with European low-hydrogen electrode

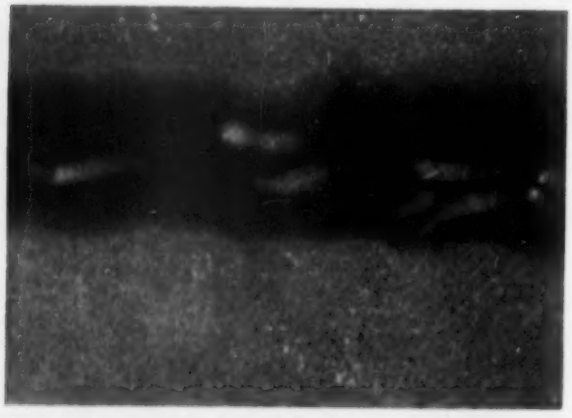


Fig. 6 Gas cavities in weld made with European low-hydrogen electrode

Well, after solving all the darkroom problems we put our full attention to getting the X-ray machine set up to start operations. Since the European-made X-ray machine weighed 160 lb, we assembled a crew of ten Indonesians and one foreman, making eleven altogether, thus making the X-ray machine readily portable.

The X-ray unit was the conventional oil-immersed type with the transformer and tube in one housing and the control in another with 50 ft of connecting cables. Waterproof flexible screen cassettes were used which

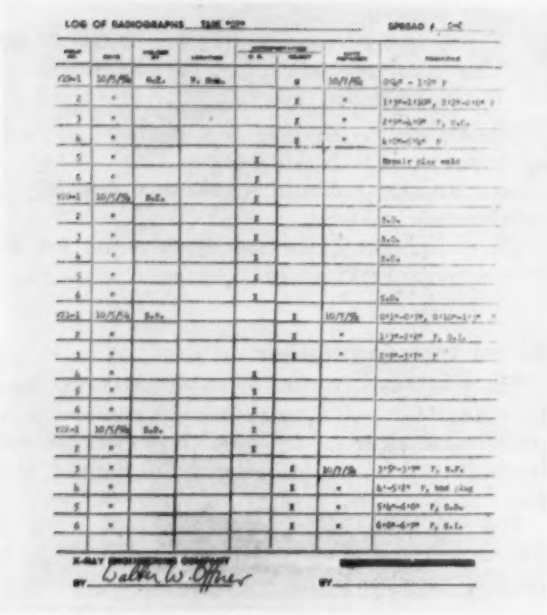

LOG OF RADIOGRAPHS

Fig. 7 Daily radiography log

were fastened to the tank walls with 32-v magnets, energized from the X-ray control box. The only item not waterproofed was the control box because it had to be taken apart three times to readjust some of the relays and to rewind a resistor which became loose during transit and burned out. A spare X-ray tube was also available in case one blew out which fortunately did not happen. To satisfy the local boiler inspector, penetrameters as specified by the Standards Association of Australia were employed (see Fig. 4).

Indonesian Labor Problem

As mentioned before, we had an eleven-man crew, who spoke no English and the author spoke no Malay, but the author had a dictionary from which he picked and remembered about twelve words which were sufficient for this job and which he spoke fluently after three days. The most essential word was "bagus" which means "good," and "Tida bagus"—"no good." Then, "O.K." which of course everybody in the world understands, and "suda" which besides many other things, means "ready." At lunchtime and in the evening when we knocked off the job, the words were "abyss" and "chow chow."

Since we took six exposures per seam, the author had to count to six—"sadu, dua, diga, ampat, lima, anam." The author loaded all cassettes and then the three men on the inside of the tank put them in place. Two men on top of the tank positioned the hook with rollers and tackle for the machine on the correct seam and the other five pulled the machine up for the exposure. We had 30 cassettes, using six per vertical seam, and we developed every five seams.

A total of 1162 films were taken in 24 days, of which 768 were of the original welds and 400 of repair welds. Eighty percent of all repairs were on plates of $^3/_4$ in.

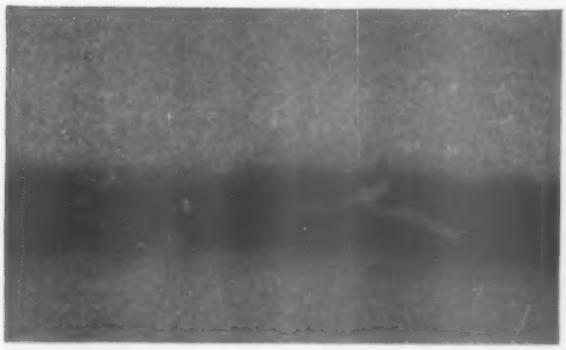


Fig. 8 Gas pinholes in weld made with American E6010 electrode

Fig. 9 Gas porosity and slag inclusions in weld made with American E6010 electrode

and over. Most of the defects were gas porosity, slag inclusion and a few areas of nonfusion (see Figs. 5 and 6).

All radiographs were taken with a 36-in. focus-film distance. The API-ASME radiographic code requires that the distance of the radiation source to the film must be a minimum of seven times the material thickness so that the films can be properly analyzed.

Figure 7 shows a copy of a typical daily report sheet on Tank D/7 and Course C.2. The "V.19" indicates Vertical Seam 19 and films 1 to 6. All seams were laid out in inches and on the right-hand side of the report sheet, the location, length and type of defect are marked. "P" stands for porosity, "S.D." for surface defects, etc.

Figures 8, 9 and 10 show typical welding defects found. On Course 1 ($^7/_8$-in. plate) and Course 2 ($^3/_4$-in. plate) all vertical welds were radiographed 100%. On Course 3 ($^5/_8$-in. plate) we radiographed the first 32 in. from the junction. However, when defects were found in the first 32 in. we radiographed the whole seam. On Course 4, we took two random radiographs of each welder's work. If the welder's work was found to be unsatisfactory, all his welds were radiographed. This radiographic procedure was adhered to throughout the job except that it was found advisable to radiograph all vertical welds made with the Europeon low-hydrogen electrode regardless of the location.

The following is the tabulation of the findings on one tank:

Course 1. 144 films of original welds; 73 of weld repairs; 27 of reweld repairs.
Course 2. 144 films of original welds; 72 of weld repairs; 31 of reweld repairs.
Course 3. 100 films of original welds; 28 of weld repairs.
Course 4. 12 films of original welds.

A total of 631 films were taken on one tank of which 231 were of first weld repairs and 58 of second weld repairs. This excessive amount of welding defects was blamed by the welders and welding supervisors on the use of the European low-hydrogen electrode and it was decided to weld the next tank with an American

Fig. 10 Poor plug weld

brand electrode made to AWS specification E6010.

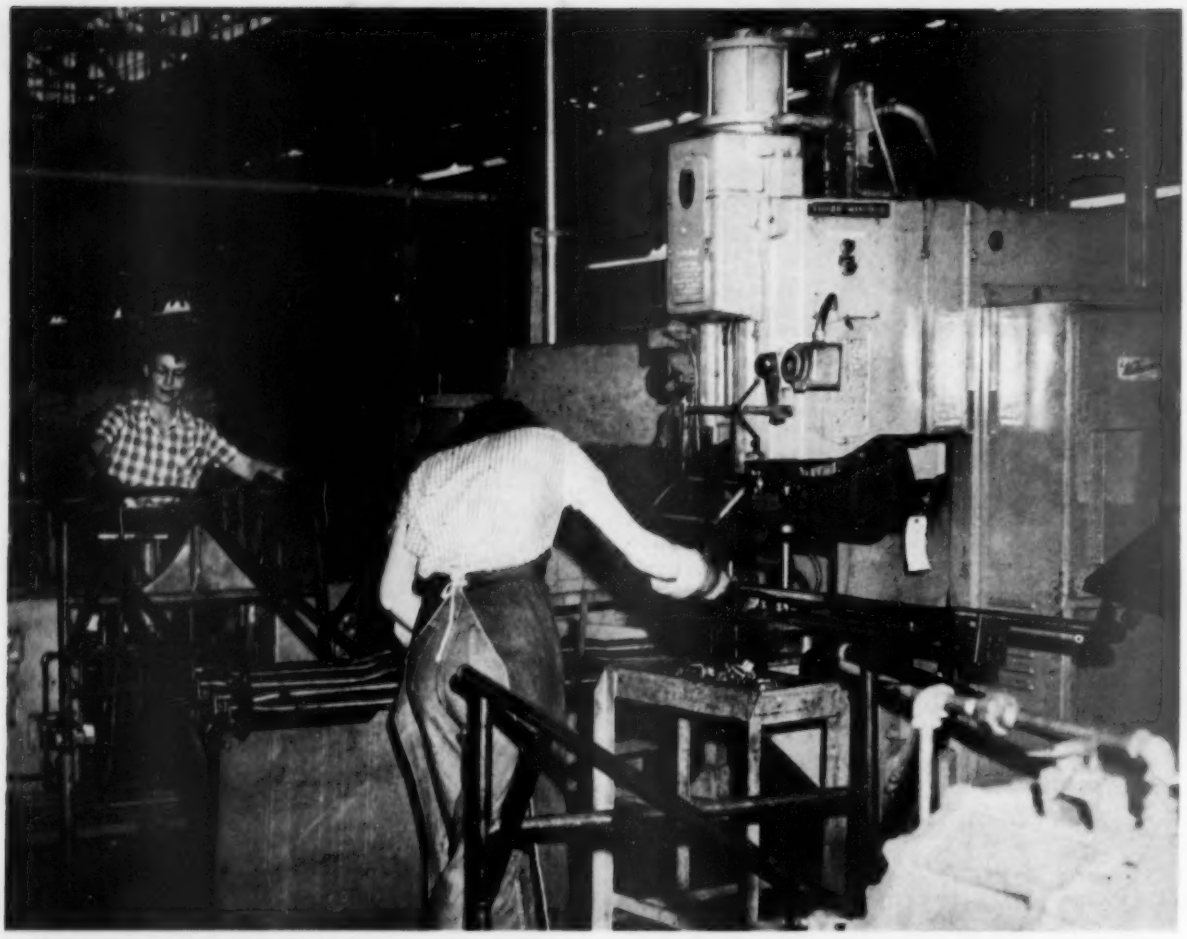
The following are the inspection results of the second tank welded with the E6010 electrode:

Course 1. 144 films of original welds; 42 of weld repairs; 1 of reweld repair.
Course 2. 144 films of original welds; 81 of weld repairs; 14 of reweld repair.
Course 3. 72 films of original welds; 25 of weld repairs
Course 4. 8 films of original welds.

Out of a total of 531 films 148 were of first weld repairs, and 15 of second weld repairs. This was an improvement on the first tank but was not conclusive enough to bear out the welders' contention that the faulty welding was caused by the use of the European made low-hydrogen electrode.

Conclusion

From the foregoing it is evident that had radiography been employed at the start of the project the weld repairs would probably have been less than 10%, thus saving money for the tank erector and the tank owner. It is most advisable that the radiographic inspection service be on the project site as soon as the first welds are made. It would be even better if all welders employed had a radiograph taken before starting tank welding in order to correct any faulty welding technique, before welds on the structure proper have to be cut out.



Typical ignitron controlled spot welder

RATINGS OF IGNITRON TUBES FOR A-C CONTROL

Characteristic properties of ignitrons differ from those of other types of electron tubes. Author clarifies meaning of published data, thereby enabling designers of ignitron-controlled equipment to draw correct conclusions and to obtain optimum results

BY P. VAN DER PLOEG

Introduction

Considering that in some cases electronic engineers experience difficulties in correctly interpreting the data of radio tubes, it is quite natural that they are puzzled by the published data of the less familiar ignitron tubes. Not only are the operating principles of these tubes entirely different from those of all other types of electron tubes, but ignitrons are, moreover, used in the high power field, to which electronic engineers are normally less accustomed. Electrical engineers, on the other

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hand, have little detailed knowledge of the various factors which determine the permissible ratings of these tubes. Finally, it should be pointed out that the terms used in the electrical and electronic fields are by no means identical, and the correct meaning of terms such as "averaging time" and "demand current" may be unfamiliar to experts in both fields.

The meaning of all the ignitron tube data is, therefore, discussed in great detail, the possibilities offered by these tubes are explained, and design engineers of ignitron-control equipment are thus enabled to obtain optimum results at a minimum of cost and trouble.

First, the data for single-phase a-c applications is dealt with exhaustively. A second section will cover an explanation of the three-phase frequency changing a-c control data. The practical use of the derived formulae is greatly simplified by introducing certain assumptions.

Single-Phase A-C Control

General

For single-phase a-c control at least two tubes are required, which must be connected in inverse parallel (see Fig. 1). Tube A passes one-half of the sine wave and Tube B passes the other half, since each tube is virtually a rectifier. An alternating current will, therefore, flow through the load. The magnitude of this current is determined mainly by the impedance of the load because the voltage drop across the tube is only a small percentage of the alternating supply voltage.

Since the tubes pass no current unless they are ignited, two tubes connected in inverse parallel can be made to act as a single-pole contractor by merely controlling the ignition of the tubes. Such an ignitron contractor can only handle a certain maximum power whether this power is drawn intermittently or continuously.

It is for this reason that ignitrons are rated in terms of the kva power that two tubes in inverse parallel are able to control at a line voltage ranging from 250 v to 600 v (rms values). This kva rating is not necessarily the continuous power that can be controlled but it is the maximum power the tubes can handle at the low duty cycles which occur in the field of resistance welding. These tubes are, in fact, mostly used for controlling the power for spot and seam welding equipment because the ratings of these tubes render them particularly suitable for this kind of equipment. During the short conduction time a heavy current passes through the tubes, although the mean value averaged over one working period is relatively low.

Heat Dissipation

The arc discharge within the tube produces a certain voltage drop across the tube. This arc voltage depends slightly on the current but in practice it may be assumed to have a fixed value. For rectifying equipment it is customary to define the arc voltage of a tube as the voltage obtained by dividing the arc losses, expressed in watts, by the average current flowing through the tube and by virtue of this definition the arc voltage is taken to be constant irrespective of the wave form of the current.

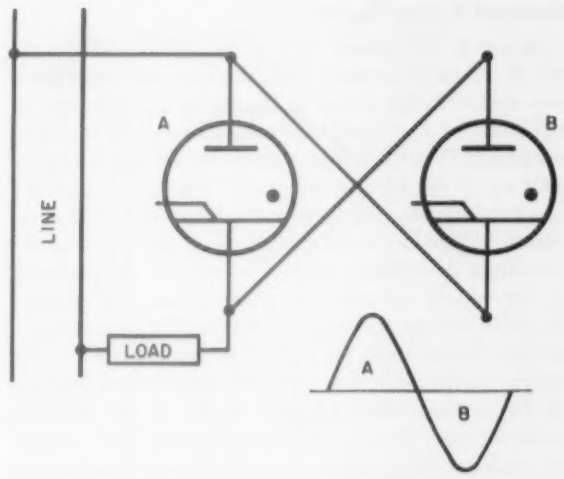


Fig. 1 Basic principle of a single-phase a-c control system incorporating two ignitrons connected in inverse-parallel

Most of the arc losses are dissipated in the cooling water which flows through the tube jacket or are carried off by conduction via the cathode and anode terminals. The arc losses determine the mercury vapor pressure within the tube. A heavy current produces a certain amount of heat, which results in a temperature rise of the inner tube parts. This increased temperature speeds up the heat transfer, by conduction and radiation, to the wall and to the cooling water, but the temperature of the mercury also rises and so does the vapor pressure.

Care must be taken that the latter never reaches such a value that the tubes become unable to resist the inverse or forward anode voltage, since this would result in arc-backs or loss of control, and this is obviously inadmissible. Consequently, a certain limit is imposed on the average current of a tube. At this maximum average current an equilibrium is established between the heat dissipating capacity and the mercury temperature and this occurs at such a level that there is no risk of damage to the tube.

With higher values of current but shorter duty cycles, the average current limit, which is valid for medium current values and long duty cycles, must not be exceeded. However, the tube voltage drop increases as the current peaks become higher and the instantaneous production of heat inside the tube may become such that this heat cannot be dissipated rapidly enough. This would result in a sudden increase of the mercury vapor pressure and would endanger the voltage resisting property of the tube. In the case of high peak currents passing through the tube, it is therefore necessary to reduce the maximum value of the average current.

Demand Power Curve

As mentioned above, at a given supply voltage the risk of arc-back increases with the mercury vapor pressure and with the value of the current. This can be explained by the fact that, immediately after current has passed through a tube, the anode voltage is rapidly built up in the reverse direction. The many mercury ions produced by the large cathode current need some time to disappear and for this reason the value of the maximum permissible current is inversely proportional to the supply voltage. In other words, the product of anode voltage and demand current (i.e., the demand power) is a constant for a given average current. The curves representing the demand power P as a function of the average current I_{av} are based on this physical phenomenon. In plotting these curves it is customary to use logarithmic scales both for the abscissa and for the ordinate (Fig. 2).

Elaborate tests have revealed that, at the maximum kva power P that two tubes connected in inverse parallel can control, the permissible average current per tube is (at the maximum) 54% of the average current allowed for continuous duty (point A of the graph shown in Fig. 2). It is, moreover, permissible to draw a maximum power of $^1/_3$ the maximum power P at an average tube current of 100% (point B of the graph shown in Fig. 2).

Between points A and B straight line interpolation is permissible. Since P represents the maximum permissible demand power, a horizontal line can be drawn through point A for an average current up to 54% of $I_{av\ max}$. For a power smaller than $^1/_3\ P_{max}$ the average current remains $I_{av\ max}$, which is represented by the vertical line through point B. The curve thus obtained is applicable to supply voltages with an rms value ranging from 250 v to 600 v. The curve representing the demand current as a function of the duty cycle is based on this representation.

Duty Cycle Curve

In order to simplify the formulas and calculations, the $P = f(I_{av})$ curve of the Type 5552 ignitron shown in Fig. 3 will be used for deriving the curve representing the demand current as a function of the duty cycle (see Fig. 4). For the sake of convenience the latter graph is also plotted on double logarithmic paper, the curves thus obtained then being composed of straight line segments.

For calculating the interpolated average current I_{av_1} (corresponding to point D of the curve shown in Fig. 3) from the demand power P_1, use is made of the formula by which the line segment AB is determined, namely:

$$P^n \times 0.54\, I_{av\ max} = (^1/_3 P)^n\, I_{av\ max},$$

therefore

$$3^{-n} = 0.54,$$

or

$$-n = \frac{\log 0.54}{\log 3} = -0.56 \qquad (1)$$

$n = 0.56$ represents the tangent of the angle α (Fig. 3). Between points A and B the product $I_{av} \cdot P^{0.56}$ is apparently constant. For the tube Type 5552 this constant C is $140 \times 400^{0.56} = 4000$.

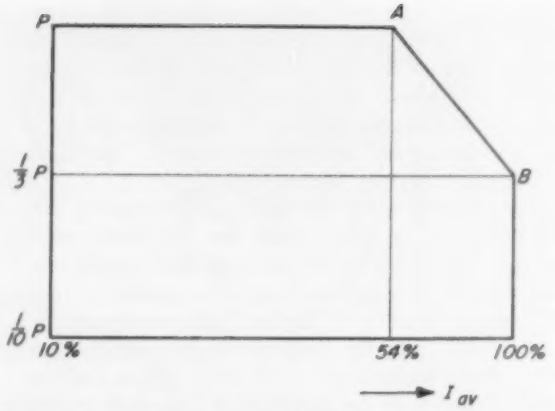


Fig. 2 Demand power curve of an ignitron. Both the demand power P and the average current I_{av} are plotted on logarithmic scales

For a given value P of the demand power, the corresponding average current is:

$$I_{av_1} = \frac{4000}{P_1^{0.56}}$$

For example for $P_1 = 800$ kva:

$$I_{av_1} = \frac{4000}{800^{0.56}} = 5 \times 800^{0.44} = 95\ A.$$

The formulae for the average currents of the tubes Type 5551, Type 5552 and Type 5553 differ only by the value of the constant C which is:

$C_1 = 56 \times 200^{0.56} = 1100$ for the tube Type 5551,
$C_2 = 140 \times 400^{0.56} = 4000$ for the tube Type 5552,
and
$C_3 = 355 \times 800^{0.56} = 15{,}300$ for the tube Type 5553

The maximum permissible power which may be controlled by a pair of Type 5552 tubes in inverse parallel is 1200 kva. For a line voltage of 250 v this gives a demand current of $I_e = 1{,}200{,}000/250 = 4800\ A_{rms}$ (point K of the rating curve shown in Fig. 4).

A duty cycle of 100% means that the tube arrangement passes current continuously, each tube conducting during half a cycle. The average anode current I_{av}', drawn during this half cycle, is obviously $\frac{2}{\pi} I_{peak}$, and the average over the entire cycle $\frac{1}{\pi} I_{peak}$.

Since the peak value of the current is equal to $\sqrt{2}$ times the rms value of the alternating current, the relationship between the average anode current I_{av}' per cycle and the rms value of the demand current I_e of two tubes connected in inverse parallel at full cycle conduction is:

$$I_e = \frac{\pi}{\sqrt{2}} \cdot I_{av}' = 2.22\, I_{av}'. \qquad (2)$$

At a duty cycle of 100% the maximum value of this demand current is therefore $I_e = 2.22 \times 140 = 311$

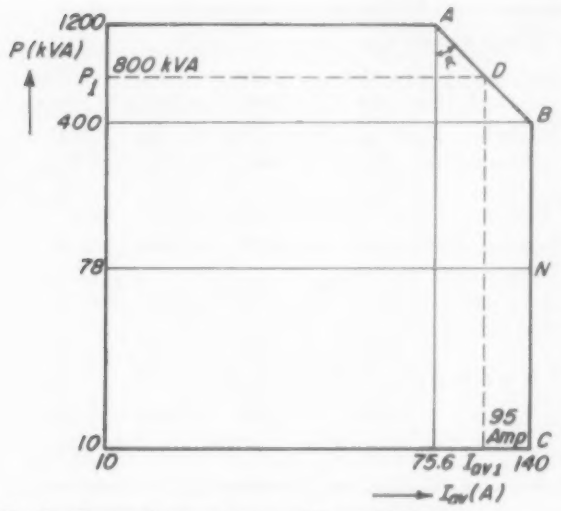


Fig. 3 Demand power curve of Type 5552 ignitron

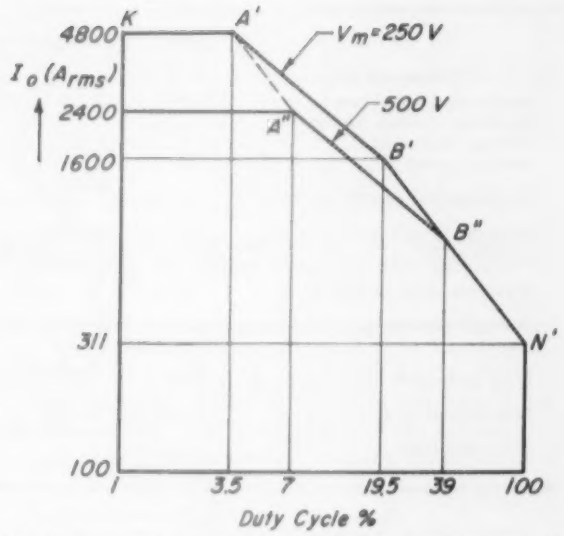


Fig. 4 Duty cycle curve representing the demand current I as a function of the duty cycle D of Type 5552 ignitron

A_{rms} (point N' of the curve shown in Fig. 4), which value is independent of the line voltage. At a line voltage of 250 v this corresponds to a power of 250 × 311 = 78 kva (point N of the curve plotted in Fig. 3).

This is obviously not the maximum permissible demand power for the maximum permissible value of the average anode current (140 A). At a duty cycle that is less than 100%, the average anode current may remain 140 A; the instantaneous rms value of the demand power increasing correspondingly up to point B of Fig. 3. The demand current corresponding to this point is $I_a = 400{,}000/250 = 1600\ A_{rms}$, which is reached at a duty cycle of $D = \frac{311}{1600} \cdot 100 = 19.5\%$ (point B', Fig. 4).

For a constant value of the average current the rms value of the demand current is inversely proportional to the duty cycle, so that a straight line can be drawn between points N' and B'.

Point A' of Fig. 4 can be defined as the point at which the average current per tube is 54% of 140 A, the associated maximum demand current being 4800 A_{rms}, which gives a duty cycle of

$$D = \frac{0.54 \times 311}{4800} \cdot 100 = 3.5\%.$$

The interpolation method adopted between points A and B in Fig. 3 gives a straight line between points A' and B' in Fig. 4. The curve is finally completed by the horizontal line KA'.

It is now quite simple to calculate the coordinates of points A'' and B'' for a line voltage of 500 V_{rms}. Point A'' should be situated at a demand current of $I_a = 2400\ A$ and a duty cycle of

$$D = \frac{0.54 \times 311}{2400} \cdot 100 = 7\%,$$

while point B'' should be situated on the inclined line $B'N'$ at a duty cycle of

$$D = \frac{311}{1/2 \cdot 2400} \cdot 100 = 39\%.$$

Averaging Time

The method of determining the averaging time will now be investigated. In the calculations given above, the tube currents and the duty cycle were calculated without taking into account the time during which current flows through the tubes, and in computing the duty cycle percentages the "sequence time" was assumed to be short. A duty cycle of 25% was, for example, understood to consist of an "on" time of 1 second and an "off" time of 3 seconds and not of an "on" time of, say, 1 minute and an "off" time of 3 minutes.

The average current on which the tube rating curves are based must be averaged over a certain period of time. Temperature will rise during a conduction period and decrease again during the subsequent period of nonconduction. At a low supply voltage a greater temperature rise is permissible than at a high supply voltage without risk of the mercury vapor pressure reaching a level at which arc back may occur. The heat developed within the tube will not cause the temperature to rise to an inadmissible level provided the average current is kept within the limits of the tube ratings for the "averaging time" that corresponds to the rms value of the supply voltage. It should, moreover, be borne in mind that the averaging time is based on a working period of half a second at the maximum permissible demand power and may not be increased correspondingly at lower demand power ratings.

The calculation of the averaging time T_{av} for a given tube is based on these two principles; this is illustrated by the following examples.

It will be assumed that Type 5552 ignitrons are used

Table 1—Ratings at a Line Voltage of 440 V_{rms}

Characteristic Data	*Formula*	*5551*	*5552*	*5553*	*Unit*
Maximum demand power	P_{max}	600	1200	2400	kva
Maximum average current	$I_{av\ max}$	56	140	355	A
Average current at P_{max}	$I_{av} = 0.54\ I_{av\ max}$	30.2	75.6	192	A
Demand power at $I_{av\ max}$	$P = 1/2\ P_{max}$	200	400	800	kva
Maximum line current at P_{max}	$I_{o\ max} = \frac{1000\ P_{max}}{440} = 2.27\ P_{max}$	1365	2730	5460	A_{rms}
Average current per tube per cycle at $I_{o\ max}$	$I_{av}' = \frac{1000\ P_{max}}{440 \times 2.22} = 1.03\ P_{max}$	615	1230	2460	A
Maximum duty cycle at P_{max}	$D = \frac{100\ I_{av}}{I_{av}'}$	4.92	6.14	7.75	%
Average current per tube per cycle at $P = 1/2\ P_{max}$	$I_{av}'' = 1/2\ I_{av}'$	205	410	820	A
Duty cycle at $P = 1/2\ P_{max}$	$D' = \frac{100\ I_{av}/0.54}{1/2\ I_{av}'} = \frac{1/0.54}{1/2}\ D = 5.55\ D$	27.23	34.1	43	%
Line current at $P = 1/2\ P_{max}$	$2.22\ I_{av}''$ or $1/2\ I_{o\ max}$	455	910	1820	A_{rms}
Averaging time	$T_{av} = \frac{50}{D}$	10.2	8.12	6.48	sec

at a line voltage of 500 V_{rms}. At the maximum demand power of 1200 kva the rms value of the demand current is 2400 A, which amounts to an average current of $I_{av}' = 2400/2.22 = 1080\ A$ per tube per cycle (cf. eq. (2)). The average anode current I_{av} at the maximum demand power is 75.6 A, which gives for the maximum duty cycle in this case 75.6/1080 = 7%. The maximum permissible "on" time is 0.5 sec, and since the maximum duty cycle is 7% (cf. the rating curve shown in Fig. 4), the averaging time is thus given by:

$$1080 \times 0.5 = 75.6\ T_{av},$$

when

$$T_{av} = \frac{1080}{75.6} \cdot 0.5 = \frac{100}{7} \cdot 0.5 = 7.1\ \text{sec}$$

The calculation of the averaging time at different line voltages and for different types of tube is now fairly simple. The averaging time of the Type 5551 at a line voltage of 250 V_{rms} can, for example, be calculated by considering that the demand power is the product of the rms value of the line voltage and the demand current, so that according to eq. (2) the maximum average current per tube and per cycle is:

$$I_{av}' = \frac{\text{demand power}}{2.22 \times \text{line voltage}} = \frac{600{,}000}{2.22 \times 250} = 1080\ A$$

Since the maximum permissible average current is 30.2 A, the duty cycle is in this case limited to 30.2/1080 = 2.8%. The maximum "on" time is again 0.5 sec, which, for a maximum duty cycle of 2.8% at the maximum demand power gives an averaging time of

$$T_{av} = \frac{100}{2.8} \cdot 0.5 = 18\ \text{sec}$$

The averaging time is thus in general given by the expression:

$$T_{av} = \frac{100}{D} \cdot 0.5 = \frac{50}{D}, \qquad (3)$$

where D represents the maximum duty cycle at the highest demand power for a given line voltage.

Ratings for Other Line Voltages

In the rating curves of ignitrons it is customary to plot only the curve for the limiting voltages which as a rule are 250 v_{rms} and 500 v_{rms}. It will, therefore, be useful to derive the rating curves for 440 v application. The corresponding characteristic data are tabulated below for several types of tubes. From these data the corresponding curves can be plotted on double logarithmic paper (see Table 1).

It should be noted that at a line voltage of 220 v the current and averaging time ratings may not exceed those valid for a line voltage of 250 v.

Phase-Retarded Ignition

All above calculations and methods of calculation are based on full cycle conduction of the tubes, i.e., it is assumed that the tubes are struck as early as possible in the sine wave and that current continues to flow through the tubes until the anode voltage drops below the arc voltage. When heat control is used in a welding machine the ignitrons are struck at a later instant in the sine wave in order to reduce the conduction time of the tubes per cycle. As a result, the average current and hence also the demand power is smaller than in the case of full cycle conduction.

This does not, however, mean that it is permissible to increase the duty cycle under these conditions. It would be incorrect to draw this conclusion from the tube data. In fact, by applying phase-retarded ignition of the tubes, the duty imposed on the tubes remains substantially the same. (If the average current drawn from the tubes during the decreased periods of conduction were equal to the maximum permissible current at full cycle conduction, the peak value of the current would become excessive.) When phase-retarded ignition is applied the load should therefore, be such that at full cycle conduction, i.e. without phase retardation, the power drawn by the same load impedance does not exceed the maximum permissible power according to the tube ratings.

Practical Examples

It will be investigated, by way of example, which tubes should be used and what the maximum number

of welds per minute is with a welding machine requiring a primary power of 800 kva and having a welding cycle consisting of an "on" time of 6 cycles and an "off" time of 60 cycles; the supply voltage is 440 v, 60 cycles.

Since two Type 5552 tubes can handle a maximum power of 1200 kva, these can be used for the purpose in view.

The line current is 800,000/440 = 1800 A, which gives for the maximum value of the average tube current per cycle $I_{av}' = 1800/2.22 = 810$ A; this corresponds to a point situated between points A and B of the curve shown in Fig. 3. According to the corresponding formula for the Type 5552, the average current is:

$$I_{av} = \frac{4000}{800^{0.56}} = 95 \text{ } A$$

as may also be read from the rating curves.

Since the average tube current per cycle $I_{av}' = 810$ A, the maximum duty cycle is 95/810 ≈ 11%.

A welding cycle consisting of an "on" time of 6 cycles of the line voltage and an "off" time of 60 cycles amounts to a duty cycle of 6/(6 + 60) = 1/11 = 9%, which is well within the permissible limits, so that the machine can operate without interruption, making one weld every 66 cycles. At a line frequency of 60 cycles the number of welds per minute is therefore 60 × 60/66- ≈ 54 welds.

If the welding cycle should consist of an "on" time of 6 cycles and an "off" time of 30 cycles (for a seam weld, for example) the maximum averaging time must also be taken into account. The averaging time for the Type 5552 at a line voltage of 440 v has been calculated to be 8.1 sec. At a maximum duty cycle of 11% this gives an "on" time of only 8.1 × 60 × 11/100 = 54 cycles within a period of 8.1 seconds, which amounts to 9 welds within 8.1 seconds. This implies that after 9 × (6 + 30) = 324 cycles, i.e. after 324/60 = 5.4 seconds, welding would have to be interrupted for 8.1 — 5.4 = 2.7 seconds. Since this is not practical, the time interval should be so chosen that one weld of 6 cycles is followed by a time interval of 54 cycles, the duty cycles being 10% in that case and 8.1 welds being made in 8.1 seconds. If a higher duty cycle is required it will be necessary to use larger types of tubes or to provide special arrangements with a larger number of tubes which are switched on in succession.

Cable Dimensions

To prevent the losses and/or the voltage drop from becoming excessive, the dimensions of the conductors should be properly chosen. The calculation of the power losses is based on the average of the rms value of the demand current, while that of the voltage drop is based on the maximum power. This will be illustrated by the following example.

Two tubes Type 5552 connected in inverse parallel can pass 1200 kva at 250 v, which amounts to a line current of 4800 A (rms value). The rms value of the current averaged over a complete welding cycle can be calculated by means of the graphical representation shown in Fig. 5.

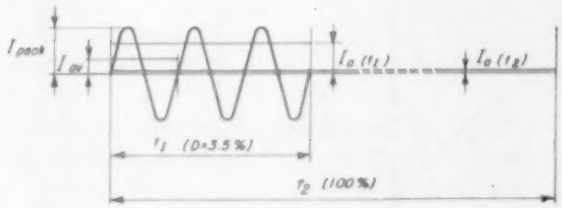


Fig. 5 Graphical representation of the demand current flowing through one pair of tubes at a duty cycle of D = 3.5%

The rms value of the demand current during the conduction time t_1 will be denoted by $I_o(t_1)$ and the rms value of the demand current averaged over one welding cycle t_2 by $I_o(t_2)$. The heat produced by each of these currents is obviously the same, therefore:

$$I_o(t_1)^2 t_1 = I_o(t_2)^2 t_2,$$

which gives

$$I(t_2)_o = I_o(t_1) \sqrt{\frac{t_1}{t_2}} = I_o(t_1) \sqrt{D}.$$

Since the maximum duty cycle D = 3.5% and $I_o(t_1)$ = 4800 A, the rms value of the demand current averaged over one welding cycle* thus becomes:

$$4800\sqrt{0.035} = 900 \text{ } A$$

When the voltage drop is of little importance, as will usually be the case for short lengths of feeder, the calculation of the cross section can be based on this current.

The cross section of the conductors for interconnecting the two tubes should be based on the average rms value of the current passing through one tube over one welding cycle.* Since two tubes pass 4800 A, each tube passes $1/\sqrt{2}$ of this current. Considering that the maximum duty cycle D = 3.5%, the rms value of the anode current is thus:

$$\frac{4800}{\sqrt{2}} \cdot \sqrt{0.035} = 635 \text{ } A$$

Three-Phase Welding Control

General

The secondary winding of a welding transformer is in principle a single-phase coil, the terminals of which are each connected to an electrode arm. Since only single-phase power is required, it is customery to use a single-phase transformer. This implies that the full welding power is drawn from the single-phase line. At a line voltage of 500 V and a power of, for example, 2000 kva, a current of 4000 A (rms value) is thus drawn during the welding time, which is of the order of a few cycles. This sudden current pulse causes a drop in the line voltage, and unless heavy section feeders are used for

* For measuring this current it is necessary to use a moving-iron meter, an electrodynamic or similar instrument which actually measures the rms value of the current. A moving coil instrument incorporating a rectifier is unsuitable for this purpose because its deflection is proportional to the average current, and the reading does not correspond to the rms value of the current unless an uninterrupted sinusoidal alternating current is fed to the rectifier. This condition is obviously not fulfilled in the case under consideration.

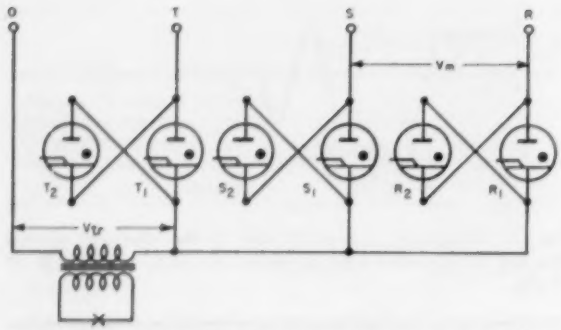


Fig. 6 Three-phase welding control system in which the total current flows through the neutral line

connecting the welding machine directly to the plant-substation transformer (which should also be adequate), or other suitable measures are taken to avoid excessive voltage drop, the result will be noticeable in other equipment connected to the same transformer or busbar system. This is obviously an inconvenience to workers in the same and adjacent buildings. The performance of other equipment may also be affected

A further disadvantage of this system is related to the fact that these large powers are used for welding heavy gage materials which usually have large dimensions, so that the secondary loop formed by the electrode arms has a rather large surface area. As a result, the self-inductance of this loop forms a high reactance to the 60 cycle current flowing through the electrode arms. Referred to the primary of the transformer, this reactance has a magnitude which sometimes reduces the power factor of the machine to 0.4 or even less. As a result, for a given amount of heat in the weld, the required apparent power will exceed the produced net heat by a factor of at least 2.5.

It is therefore highly desirable to distribute the current demand evenly over the three phases of the supply system and to improve the power factor. This can be achieved by reducing the frequency. When the frequency is changed, for example, from 60 cycles to 12 cycles, the influence of the secondary loop reactance is reduced to 20% of its original value which results in a considerable improvement of the power factor. The desired reduced welding frequency can be obtained from the three-phase welding control system which is discussed below. From an electrical point of view, this system has some resemblance to polarity-changing rectifying devices.

Basic Principle of Operation

It will be assumed that a three-phase supply system with neutral point is available. Three pairs of ignitrons in inverse parallel are connected between the phases R, S and T and the primary of the welding transformer, the other terminal of this primary being connected to the neutral point O as shown in Fig. 6.

When the Tubes R1, S1, T1 pass current in succession a direct current will flow through the transformer primary. After a few primary cycles the ignition of the Tubes R1, S1, and T1 is interrupted, so that current ceases to flow. Subsequently, the Tubes R2, S2, and T2 are fired, passing current in succession in the opposite direction.† As a result, a direct current will again flow through the transformer primary, but in the opposite direction. If this procedure is repeated, a nonsinusoidal alternating current will flow through the transformer primary. The duration of each half cycle and hence the "welding frequency," can easily be varied by controlling the number of primary cycles during which the Tubes R1, S1 and T1 or the Tubes R2, S2, and T2 are made conductive.

In the circuit of Fig. 6 the peak inverse voltage of the tubes is equal to the peak value of the line voltage V_m, which is $V_m\sqrt{2}$. The voltage across the welding transformer—primary can be calculated from the formula for three-phase, half-wave rectification, namely:

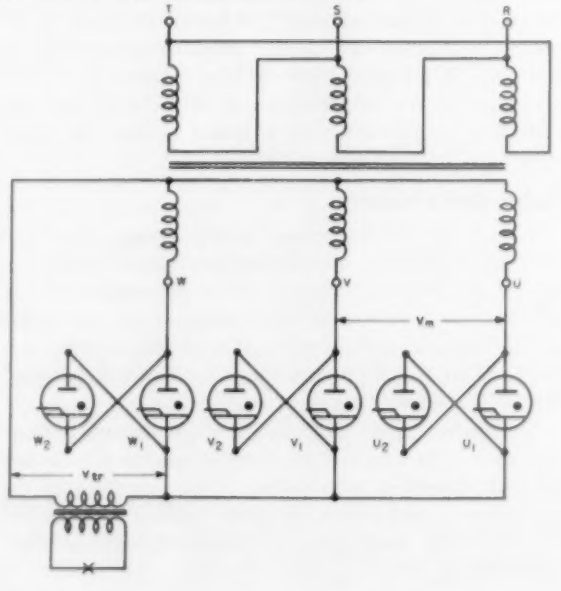
$$V_{tr} = 1.17\frac{V_m}{\sqrt{3}} = 0.675V_m \qquad (4)$$

it being assumed that this voltage has a rectangular waveform with a magnitude equal to the mean value of the rectified voltage.

It should be realized that in this circuit an alternating current with the welding frequency flows through the neutral line to the substation transformer, so that the latter operates as a transformer for a three-phase rectifier. Normal power supply transformers are, however, designed for a neutral wire with a cross section

† In order to avoid the occurrence of undesirable phenomena, a short interval should elapse before one set of tubes takes over the function of the other set of tubes.

Fig. 7 Welding control system similar to that shown in Fig. 6 but with additional transformer with delta-connected primary and star-connected secondary



which is approximately half the cross section of the phase conductors, the phase currents being substantially balanced so that the neutral line is scarcely loaded. In the circuit described, however, the sum of the phase currents pass in one direction through the neutral line during one half of the welding frequency cycle and in the opposite direction during the other half cycle. The neutral wire should therefore have approximately *twice* the size of the phase conductors and the internal connection from the physical star point of the transformer to its terminal should be dimensioned accordingly.

In view of the difficulties which this circuit causes for the lay-out of the supply cables, it is advisable to link-in an additional transformer with delta connected primary and star connected secondary between the substation transformer and the welding machine (see Fig. 7). In this way it is also possible to adapt the transformer secondary voltage to the ratings of the ignitrons. An autotransformer can also be used for this purpose instead of a transformer with separate windings.

It should be noted that in view of the low frequency of the current flowing through the welding transformer, the latter must be specially designed for the purpose in view.

Figure 8 shows the circuit of a somewhat different system in which a special welding transformer having three separate primary windings is used. The ignitrons are connected in inverse parallel and each winding, in series with a pair of tubes, is connected between two phases. The operation of the circuit may be explained as follows.

Assume the Tube A1 to be conducting so that current flows from phase R through the primary coil A to phase S. After a delay of 120° Tube B1 will strike and as a result current will flow through the primary coil B; the current through coil A will cease as soon as current starts to flow through coil B. After another delay of 120° Tube C1 will fire and current will start to flow through coil C. 120° later the current will in turn be transferred from coil C to coil A, and this procedure can be repeated several times. Each current pulse magnetizes the transformer core, and since the current pulses flow in the same direction, the transformer flux is gradually built up from zero to its maximum value.

After this maximum value has been reached, the procedure described above is stopped and followed by a similar procedure, but now the Tubes A2, B2, and C2 are involved instead. As a result, current will flow in the opposite direction through the primary coils of the transformer, causing the flux to be built up in the reverse sense. The flux in the transformer core thus changes direction at a frequency which is lower than the line frequency, and this alternating flux induces a voltage in the secondary coil to which the electrodes of the welding machine are connected.

The essential difference between the circuits of Figs. 6–7 and Fig. 8 is that in the former circuits the supply voltage is rectified and connected to the welding transformer primary, whereas in the latter circuit the primary current is rectified and fed to separate coils. Both systems are similar in that an alternating primary transformer flux of relatively low frequency is produced and this in turn produces the desired welding current.

Calculation of the Essential Data

Tube Ratings

The tube ratings will be evaluated on the basis of the circuit shown in Fig. 8.‡ In this circuit A, B and C may each be regarded as one primary coil of a single-phase transformer. When Tube A1 is conducting and current is passing through coil A from R, voltages will be induced in the coils B and C which are not in phase with the line voltages applied to these coils but differ 120° in phase angle.

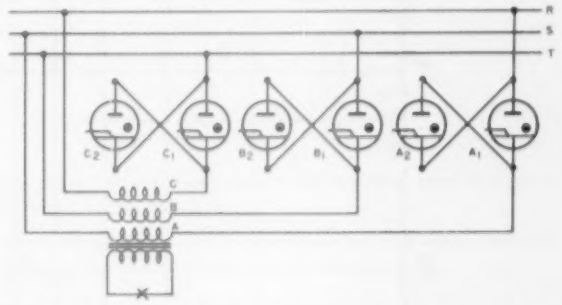


Fig. 8 Three-phase welding control system incorporated a special welding transformer with three separate primary windings

Since the coils A, B and C have an equal number of turns, the voltages across these coils will exceed the line voltage V_{rms} between the phases S and R by a factor of $\sqrt{3}$. The peak forward and peak inverse voltages of the tubes included in these circuits are $\sqrt{2}$ times this rms voltage,

$$V_{peak} = V_{rms} \cdot \sqrt{2} \cdot \sqrt{3} = V_{rms}\sqrt{6}\S \qquad (5)$$

When Tube A1 is conducting for 120°, the waveform of the current may be assumed to be rectangular. This assumption is only permissible when the load is purely inductive and the switching time is zero. In practice this will not be the case because the voltage is part of a sine wave and the current will have a similar waveform whenever the load is partly or entirely resistive. Also, the switching time cannot be made infinitely small.† For the sake of simplicity, however, the deviation from the rectangular waveform and the switching time will be disregarded.

The average current I_{av} can be calculated as follows from the peak current I_{peak}. During the "on" time of the Tubes A1, B1, and C1 (i.e. during half a welding frequency cycle) the average current of these tubes will

‡ From the point of view of tube duty the welding system shown in Figs. 6 and 7 is identical to that in Fig. 8, so that there is no need to calculate the data of each system separately.

§ This formula is identical to that applicable to the peak inverse voltage of a rectifying tube in a three-phase, half-wave rectifying circuit, the phase voltage of which is equal to the line voltage of Fig. 8.

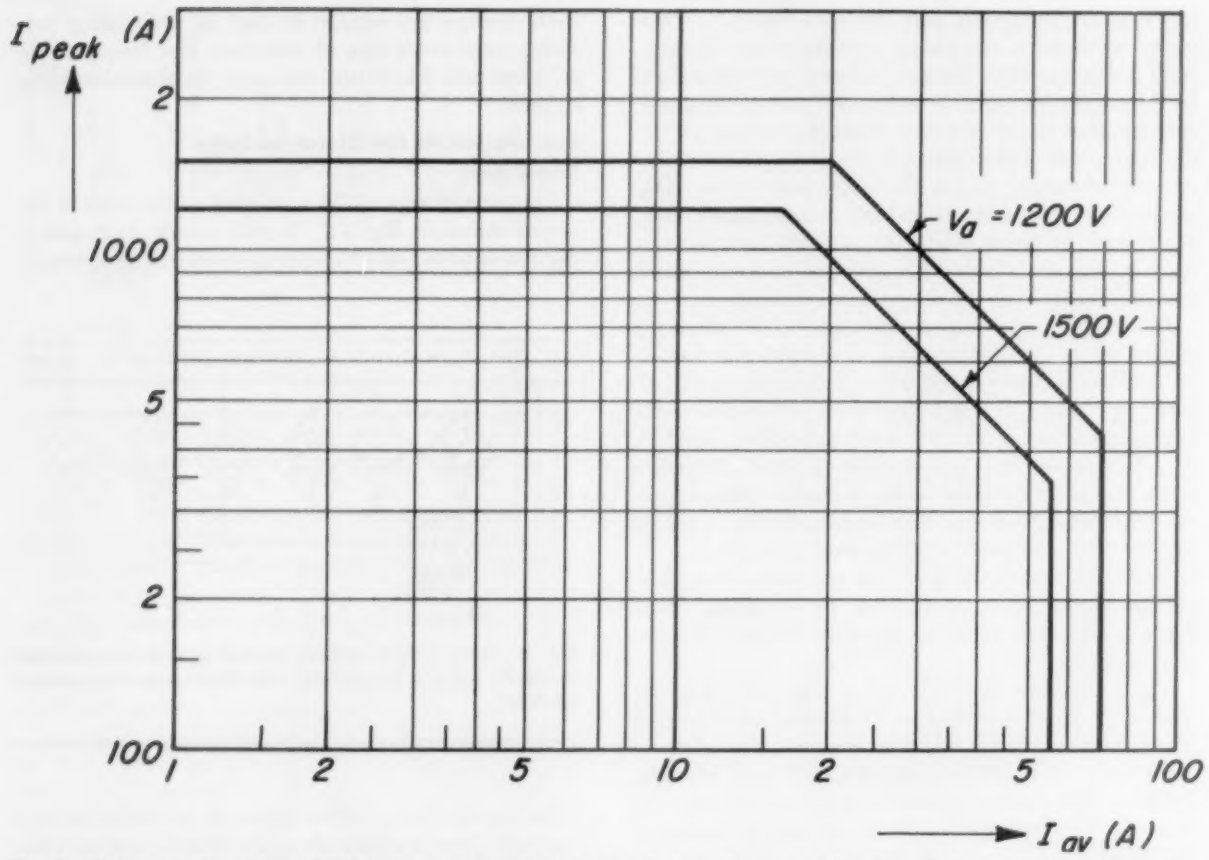


Fig. 9 Characteristics of type 5822 ignitron representing the peak current I_{peak} as a function of the average current I_{av} for two different values of the peak forward and peak inverse anode voltage V_a.

be $^1/_3\ I_{peak}$, as in the case of normal three-phase, half-wave rectifiers with inductive load. During the other half of the welding frequency cycle the Tubes A2, B2, and C2 will conduct with a peak current of $^1/_3\ I_{peak}$, the other tubes being non-conducting. During a complete welding frequency cycle the average tube current I_{av} is therefore:

$$I_{av} = \frac{1}{2} \cdot \frac{1}{3} I_{peak} = \frac{1}{6} I_{peak} \qquad (6)$$

This peak current and the average current may not be drawn during an infinite number of welding frequency cycles; this can be inferred from the data of the Type 5822 ignitron given in Table 2.

The ratings can also be derived from the tube characteristics shown in Fig. 9, representing the peak anode current I_{peak} as a function of the average anode current I_{av} with the peak forward and peak inverse voltage V_a as parameter.

The calculations will be based on the data for V_a = 1500 V given in the second column of Table 2. (The ratings given in the second column result in the same output power, since the product $V_a \cdot I_{p\ max}$ is equal for both columns.)

Table 2—Ratings, Type 5822 Ignitron

Peak forward and peak inverse anode voltage V_a	1200 V	1500 V*
Max peak current $I_{p\ max}$	1500 A*	1200 A
Corresponding average current I_{av}'	20 A	16 A
Max average current I_{av}	70 A*	56 A
Corresponding peak current I_{peak}	420 A	336 A
Max averaging time T_{av}	6.25 sec	
$I_{av}/I_{peak}(T_{av}$ = 0.2 sec)	0.166	
Frequency range	50–60 cycles	

* These values must never be exceeded.

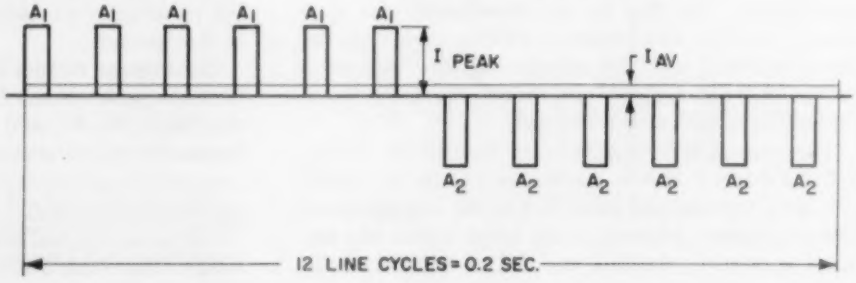


Fig. 10 Graphical representation of the current flowing through one pair of tubes

As shown above, the peak current is six times the average current in three-phase half-wave welding circuits, so that the condition $I_{av}/I_{peak} = 0.166$ is inherently fulfilled. The maximum number n of current pulses that may be supplied by one tube during 0.2 sec can be calculated from this condition. If the line frequency is 60 cycles, then a time of 0.2 sec will correspond to $0.2 \times 60 = 12$ line frequency cycles. It may be quoted as a close approximation that during this period, n current pulses, each having a duration of $^1/_3$ cycle and a magnitude of 1200 A, flow through the tube. This number of ampere-cycles should be equal to the product of the average current and 12 cycles, which gives:

$$n \cdot \frac{1}{3} \cdot 1200 = \frac{1}{6} \cdot 1200 \cdot 12$$

thus:

$$n = 6$$

This is illustrated in Fig. 10 for the Tubes A1 and A2. The number of times r that this pattern may be repeated within the maximum averaging time T of 6.25 sec can now be calculated by means of the average current I_{av}' corresponding to the maximum peak current quoted in the table above. Since the average current during 0.2 sec is $0.166 \times 1200 = 200$ A, the following condition should be satisfied:

$$0.2 \times 200r = I_{av}' \cdot T_{av} = 16 \times 6.25,$$

which gives:

$$r = 2.5.$$

The calculated values of n and r have the following practical significance: n denotes the number of current pulses per tube for one welding frequency cycle. The maximum duration of one welding frequency cycle is 0.2 sec, which gives for the lowest permissible welding frequency $1/0.2 = 5$ cps. The maximum duration of the welding time is $0.2\ r = 0.5$ sec during each period of 6.25 sec; at the maximum output the maximum duty cycle is therefore:

$$D_{max} = \frac{0.5}{6.25} \cdot 100 = 8\%$$

Primary Currents and Power Factor

The various currents in the primary conductors can be calculated by means of the schematic representation shown in Fig. 11.

A square-wave current as shown in the diagram of Fig. 10 flows in turn through the coils A, B and C of the transformer primary (Fig. 8). The peak value of this current is 1200 A and the sum of the current pulse time per welding frequency cycle is one third of the duration of this cycle, which gives an rms current value of $\sqrt{^1/_3} I_{peak}$.

The current in phase R is composed of the current pulses occurring in the coils A and C, and since these current pulses do not flow simultaneously but in succession, the rms value of the line current is:

$$I_m = \sqrt{\frac{1}{3}} \cdot \sqrt{2} \cdot I_{p\,max} = \sqrt{\frac{2}{3}} \cdot 1200 = 980 \text{ A}$$

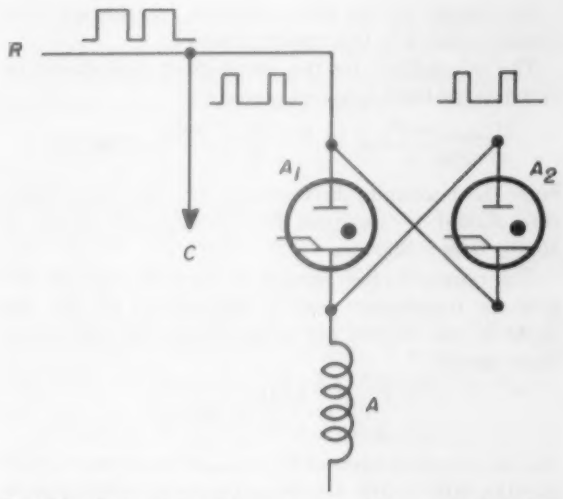


Fig. 11 Part of the three-phase welding control system shown in circuit of Fig. 8

The rms value of the maximum line voltage is obviously:

$$V_m = \frac{V_s}{\sqrt{6}} = \frac{1500}{\sqrt{6}} = 612 \text{ V},$$

which gives for the power drawn from the three-phase supply:

$$\text{Pi} = I_m \cdot V_m \cdot \sqrt{3} = 980 \times 612 \times \sqrt{3} = 1040 \text{ kva}.$$

It will be assumed, for calculating the output power, that output voltage and current have a rectangular waveform. This assumption implies that the output current may be regarded as consisting of direct current pulses which alternate at a rate depending on the welding frequency. The output current referred to the primary is obviously 1200 A, while the output voltage referred to the primary is equal to the average direct voltage obtained by means of three-phase, half-wave rectification at a line voltage V_m of 612 V, i.e. $1.17 \times 612 = 720$ V. Disregarding losses, the output power is therefore:

$$P_s = 1.17\ V_m \cdot I_{peak} = 720 \times 1200 = 860 \text{ kva},$$

which, neglecting the self-inductance of the load circuit, may be set equal to 860 kw.

The maximum power factor is therefore:

$$\cos \varphi = \frac{860}{1040} = 0.826$$

which is identical to that of a normal three-phase, half-wave rectifier.

Transformer and Cable Dimensions

The demand power of each pair of tubes, connected in inverse parallel, amounts to:

$$P_{demand} = V_m \cdot \frac{I_{p\,max}}{\sqrt{3}} = 612 \cdot \frac{1200}{\sqrt{3}} = 424 \text{ kva}$$

The design of the three primary transformer coils should be based on this apparent power.

The calculations for the transformer core should be based on the total apparent power, i.e.

$$\frac{3P_{demand} + P_c}{2} = \frac{(3 \times 424) + 860}{2} = 1066 \text{ kva}$$

Since the maximum duty cycle is 8%, the transformer core should be designed for an apparent power of $1066\sqrt{0.08} = 300$ kva.

The required cross section of the wire used for the primary transformer coils is determined by the rms value of the current per phase during the conduction time, namely:

$$\frac{I_{p\,max}}{\sqrt{3}} = \frac{1200}{\sqrt{3}} = 694 \text{ A},$$

which, for a duty cycle of 8% amounts to an rms current of $694\sqrt{0.08} = 197$ A averaged over one welding cycle. The rms value of the anode current of each ignitron is thus $197/\sqrt{2} = 139$ A.

These values can also be determined by the following argument. At the maximum peak current $I_{p\,max}$ of 1200 A the corresponding average current I_{av}' is 16 A. From the point of view of heat dissipation, the cables to the ignitrons should be adequate for the rms value of the current which may, to a first approximation, be assumed equal to the square root of the product of these two currents**; from this it follows that the rms value of the anode current of each ignitron is $\sqrt{1200 \times 16} = 139$ A. The rms value of the current flowing through the transformer primary coil is obviously $\sqrt{2}$ times this value, i.e. $139\sqrt{2} = 197$ A.

The supply cable conductors should be able to carry a current of $\sqrt{2}$ times this value, i.e. $197\sqrt{2} = 280$ A (rms value).

It should be realized that these figures are based on heat losses and that it may still be necessary to increase the calculated cross sections to reduce voltage drop.

Limitations of the Above Method

For all above calculations it is assumed that no losses occur in the tubes, transformers, conductors, etc., and that the waveforms of the currents and voltages are ideal. As in all other branches of engineering, however, these ideal conditions never occur in practice.

This is illustrated by the fact that the secondary current gradually increases according to an exponential law as indicated by the curve of Fig. 12. In this curve the total secondary current has been plotted as a function of time. The cross-shaded areas indicate the current pulses supplied by one tube. It will be clear that the peak currents will only reach their highest values toward the end of the welding frequency half cycles. The back emf produced by the self-inductance is, in fact, so high at the beginning of these half cycles that the difference betweeen the actual supply voltage and the back emf is small, and the result of this is a relatively low current. Since the peak current is one of the limiting factors imposed by the tubes, and the highest permissible peak current is only reached toward the end of each half cycle, the actual output power will consequently be smaller than the calculated value.

** This simple rule for calculating the rms value of currents is valid for square-wave pulses only, and can be explained as follows. It will be assumed that the peak current flows during a time t which is part of the averaging time T_{av}, hence:

$$I_{p\,max}\, t = I_{av}\, T_{av}$$

Multiplication by $I_{p\,max}$ gives:

$$I_{p\,max}^2\, t = I_{p\,max}\, I_{av}\, T_{av}$$

Denoting the equivalent rms value of the current by I_{rms}, it also follows that

$$I_{p\,max}^2\, t = I_{rms}^2\, T_{av},$$

thus

$$I_{rms}^2\, T_{av} = I_{p\,max}\, I_{av}\, T_{av}$$

or

$$I_{rms} = \sqrt{I_{av}\, I_{p\,max}}$$

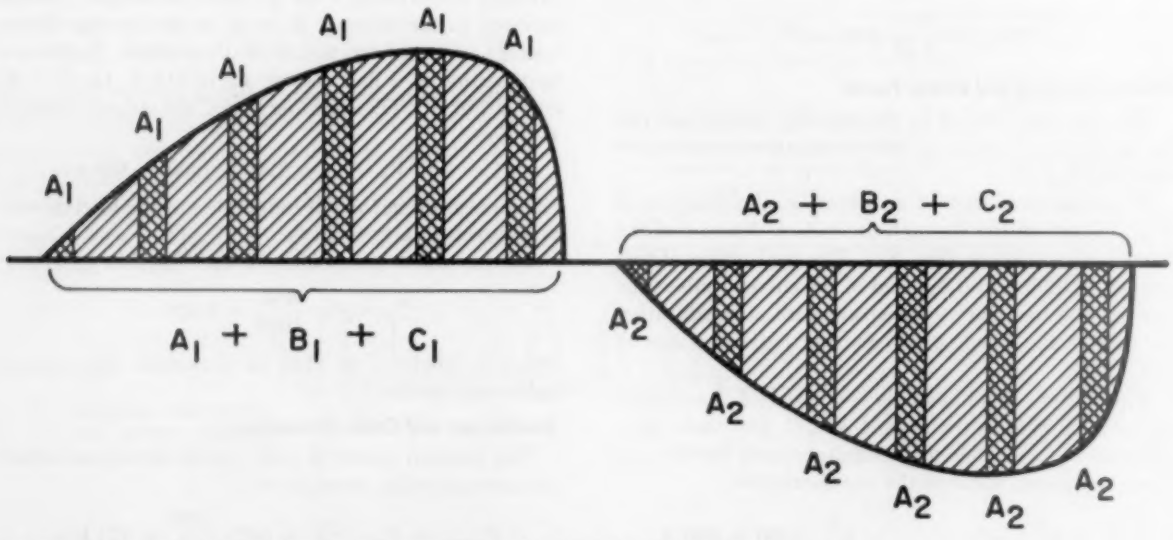


Fig. 12 Variation of the total secondary current as a function of time (idealized)

Furnace Temperature Control

General

Although the three-phase control system, discussed in the preceding section, has been primarily developed for welding control (which is an on-off application), it can also be used to advantage for feeding and controlling electric furnaces, an uninterrupted alternating current being supplied to the heating element.

In particular in high-temperature furnaces of the tubular type, operating at temperatures ranging from, say 1000° C to 2000° C, all types of refractory insulating material commonly used for furnace construction become more or less conductive; this can give rise to electrolysis of the insulating material and might endanger the life of the operator, so that the applied voltage should be as low as possible. In view of the large amount of energy required, the furnace should, moreover, be fed from a three-phase supply. The use of a three-phase step-down transformer suggests itself for the purpose, but it is impracticable to provide a helically wound heating element with taps to operate at such high temperatures. Splitting the element into three equal parts would result in two "cold" areas in the furnace due to the heat partially carried off by the supply leads, which must necessarily be of very heavy gage. For these reasons it is necessary to use a heating element consisting of a single helically wound coil.

The obvious method of feeding such a coil is to transform the three-phase supply to a single-phase supply. Moreover, since it is usually desirable to control the temperature, a three-phase frequency changing system, equipped with ignitrons, offers a practical solution. Such a system is essentially the same as that used for three-phase welding control. The alternating current output, however, flows continuously instead of intermittently.

Calculation of the Essential Data

For the type of service outlined above use is made of those tube ratings which have not yet been considered. For the Type 5822 ignitron the data are given in Table 1. The output power obtainable can be calculated in the same manner as that of a welding control system.

The ratio of the peak current to the maximum average current of this tube $I_{peak}/I_{av} = 6$, so that it can operate continuously at the rated peak and average currents in the circuit of Fig. 8 (cf. eq. 5).

At the maximum permissible supply voltage of $V_a/\sqrt{6} = 1500/\sqrt{6} = 612$ V, six tubes can supply a maximum output power of

$$P_o = 1.17 \times 612\, I_{peak} = 1.17 \times 612 \times 336 = 240 \text{ kw},$$

zero losses and zero phase shift being assumed.

The demand power of each transformer primary coil, and thus of each pair of tubes is

$$P_{demand} = V_m \cdot \frac{I_{peak}}{\sqrt{3}} = 612 \cdot \frac{336}{\sqrt{3}} = 118 \text{ kva}$$

The currents flowing through the conductors, and the required conductor cross sections, can now easily be calculated according to the methods given above for three-phase welding control, bearing in mind, however, that the transformer secondary load is now continuous instead of intermittent. The apparent power for which the transformer should be designed is:

$$\frac{P_{demand} + P_o}{2} = \frac{(3 \times 118) + 240}{2} = 297 \text{ kva}$$

The cables to the ignitrons should be capable of passing a current with an rms value of:

$$I_{a\ rms} = \sqrt{I_{av} I_{peak}} = \sqrt{56 \times 336} = 137 \text{ A}$$

while the primary coils of the transformer should be designed for an rms current of $137\sqrt{2} = 194$ A. The rms value of the current flowing through the supply cables is thus $194\sqrt{2} = 275$ A.

At a supply voltage of 440 V the maximum average current corresponding to a given peak current may not be increased in proportion to the latter, since I_{av} and I_{peak} must never exceed the maximum permissible values of 70 A and 420 A respectively (see ratings on Type 5822). As a result, the maximum output power will be:

$$P_o = 1.17 \times 440\, I_{peak} = 1.17 \times 440 \times 420 = 216 \text{ kw},$$

while the demand power of each transformer primary coil and of each pair of tubes will be:

$$P_{demand} = 440 \cdot \frac{I_{peak}}{\sqrt{3}} = 440 \cdot \frac{420}{\sqrt{3}} = 106 \text{ kva}$$

At a line voltage of 440 v the transformer should thus be designed for an apparent power of

$$\frac{3\, P_{demand} + P_o}{2} = \frac{(3 \times 106) + 216}{2} = 267 \text{ kva}$$

and the rms value of the anode current of each ignitron is:

$$I_{a\ rms} = \sqrt{I_{av} I_{peak}} = \sqrt{70 \times 420} = 172 \text{ A}$$

The transformer primary coils should thus be designed for an rms current of $172\sqrt{2} = 243$ A, and the rms value of the current flowing through the supply cable is $243\sqrt{2} = 344$ A.

Important Note

It should be realized that the powers, currents and voltages, as calculated, are based on the published ratings of the ignitrons. With this type of tube it is customary to publish the absolute maximum values for the various ratings. In designing installations incorporating these tubes, it is therefore, essential to take this fact into account and to make sure that the published maximum ratings are not exceeded under the most unfavorable conditions, that is when the total effect of spread in the transformer and components and line voltage fluctuations result in the heaviest use of the tubes. The nominal values of the powers and currents for which the equipment is designed must therefore be kept lower than the rated values.

Since the tube manufacturer cannot anticipate how great the spread between the nominal and the maximum value may be, it is common practice with ignitrons to publish the limiting values of the tube parameters.

HIGH-SPEED WELDING OF GAGE MATERIAL

BY R. A. KUBLI AND T. J. McELRATH

Characteristics of submerged arc welding and inert-gas-shielded processes indicate that they can be readily used for high-speed welding applications

Introduction

The trend in this country is to examine critically every welding process operation with the aim of reducing unit costs while maintaining or increasing production. Automation is becoming increasingly important. High-speed welding implies automation with attendant high-production rates at lower unit costs. Welding, although a long-established process, is just beginning to attain its rightful place as a high-production automatic tool. Those of us who must deal with welding problems daily, cannot help recognizing the need for automatic high-speed welding.

The newer welding processes now feature automatic operation and high arc-travel speeds. These two features reduce production costs by lowering direct labor costs, the cost of overhead and the charges for amortization of equipment per unit produced.

When examining an existing operation for the purpose of reducing costs, the possibility of employing high-speed welding cannot be overlooked. The designer, supervisor or welding engineer, may choose submerged-arc welding or one of the new inert-gas-shielded processes for the high-speed welding of gage materials.

The high-speed application of submerged arc welding and the inert-gas-shielded processes represent new tools for industry. Each appears destined for large-scale

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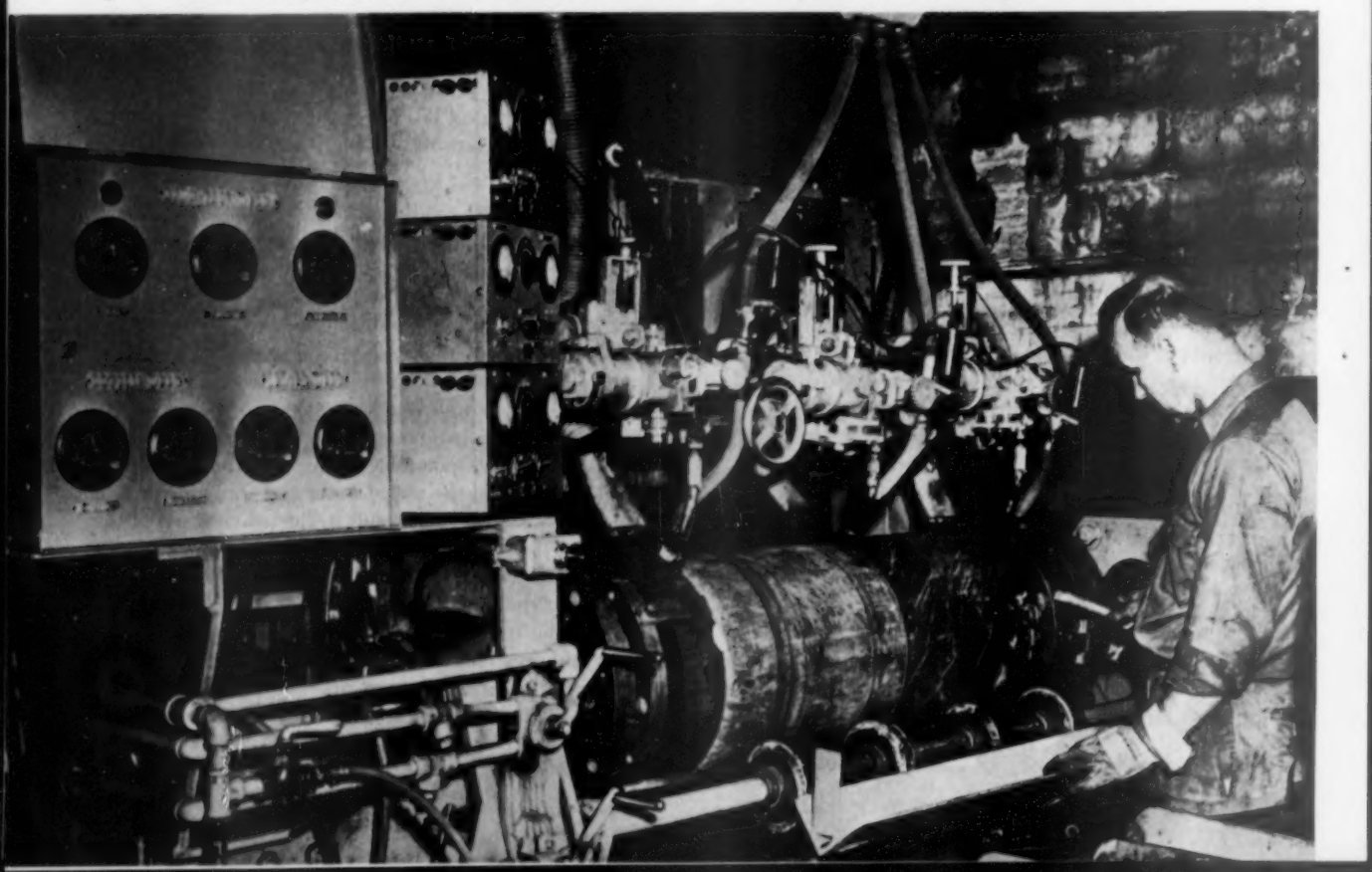
Fig. 1 Fabrication of propane cylinders with high-speed single- and multiple-electrode submerged arc welding



use, and each has characteristics which best suit it for certain classes of work. A knowledge of these characteristics is needed to select the proper process or combination of processes to obtain the best results at lowest unit cost. The purpose then of this paper is to describe these characteristics and to relate them to process selection and performance on materials ranging in thickness from 0-gage (0.312 in.) down to 18-gage (0.047 in.) or less.

Definition of High-Speed Welding

Higher production of welded parts at minimum cost can be achieved in several ways. For instance, it may be expedient to provide more welding heads or torches, all operating at their former travel speed. As an example with the installation shown in Fig. 1, a tank requiring three-girth welds could be produced in approximately one-third of the time if the three seams could be made simultaneously. Another method of achieving the objective would be through automatic jigging or sequencing, which in effect would raise the welding duty cycle.

Higher production and lower costs may also be achieved by a change of welding process to obtain a drastic reduction in cleaning time. For example, flux removal required in the flux-coated arc welding of low alloy steel is reduced or completely eliminated by choosing a process which allows rapid flux removal or which involves no flux at all. A notable example of this feature is the application of inert-gas tungsten-arc welding to the fabrication of pipe.

Although such factors affect the over-all productivity of the welded part, emphasis in this paper is placed on arc travel speed. Arc travel speed is most important, either alone or in combination with other factors, in increasing production or reducing costs. However, arc travel speed is relative. For instance, 80 ipm is considered fast for welding 0-gage ($^5/_{16}$-in.) steel, but it is only a routine speed for welding 14-gage (0.078-in.). Similarly, 12 ipm is fast for welding heavy aluminum but has been routine on 16-gage aluminum for some time.

General Requirements for High-Speed Welding

In any study of a process or product with the intent of applying high-speed welding methods, certain factors must be considered. These factors are listed below:

1. Welding process selection.
2. Joint design.
3. Jigging and fixturing.
4. Welding equipment requirements.

These factors are mutually dependent. They must, therefore, be studied in relation to each other. Referring to process selection, discussion will be confined to submerged arc welding and the inert-gas processes. Two inert-gas processes are involved: tungsten-arc inert-gas welding and consumable-electrode inert-arc welding.

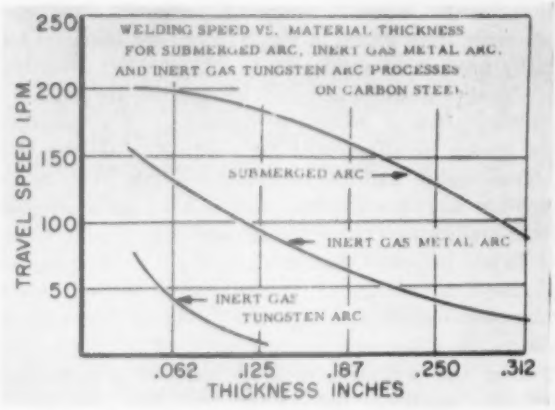


Fig. 2 A comparison of high-speed welding performance on carbon steel by type of welding process

Choosing the Right Welding Process

General

Generally, decisions on process must be made first, since the selection of the process influences joint design, jigging requirements and the purchase of welding equipment. Sometimes, process selection is clear-cut and simple. Where more than one process may be used, however, decisions are usually based on economic considerations or on special process characteristics.

In choosing a process for high-speed applications, the metal to be welded sometimes serves to narrow the field of selection. For example, for nonferrous metals, the inert-gas processes are used almost exclusively. With carbon steel, submerged arc welding merits first consideration due to its low cost. For stainless steel, the inert-arc processes are used most widely, although submerged arc welding can be applied.

Carbon Steels

A. Cost and Speed Comparison. Experience on a great many applications indicates that the cost of consumables for submerged arc welding is approximately one-half that for consumable-electrode inert-gas welding. Because of cost and because submerged arc welding is generally faster, it is the first choice for carbon steel applications. The inert-gas processes would be chosen where the use of granular compositions is considered undesirable or where visibility of the welding operation is necessary. The inert-gas processes are generally more suitable than submerged arc welding for 16-gage or thinner materials or for thin edge welds.

There is a maximum welding speed which can be obtained with each of the three processes under discussion here. For carbon steel, these speeds vary with thickness as shown in Fig. 2. Weld bead malformation generally tends to occur when operating above the speeds indicated in this graph. Future increases in welding speed will depend upon development of improved techniques.

To illustrate the relative speed advantage of sub-

merged arc welding compared with the inert-gas processes, data shown in Fig. 2 have been obtained for many production applications. They reflect a variety of process variations and joint designs but are generally representative of process performance. For instance, the speeds for submerged arc welding on the heavier gages employ multiple-electrode welding. For tungsten-arc inert-gas welding, speeds have been selected from applications using the flanged-edge type of joint. It should be noted that submerged arc welding enjoys a speed advantage of approximately 50 ipm over consumable-electrode inert-gas welding throughout the entire range of gage materials. The curve illustrating the performance of submerged arc welding becomes relatively flat as the thickness goes down. The curve representing the consumable-electrode inert-gas process continues to rise in the range of the thin gages, indicating the possibility of increased speeds on very thin materials.

Tungsten-arc welding as shown by the lower curve, is in most instances, a relatively low-speed process. Where filler wire is used with the tungsten-arc, speeds are generally even lower than those shown on the curve. However, the curves represent average conditions.

B. Submerged Arc Welding. There are several forms of single and multi-electrode submerged arc welding which can be used for high-speed joining of carbon steel. These are:

1. Single-Electrode Welding: The simplest submerged arc welding uses a single electrode operating in conjunction with a conventional d-c or single-phase a-c power supply. This technique can be applied to all thicknesses. It has been most successful as a high-speed process on thicknesses up to and including 10-gage.

2. Multiple-Electrode Welding (Parallel Power Connection): In the range of thicknesses from 10-gage (0.140 in.) to 0-gage (0.312 in.), a multiple-electrode technique can be used to advantage. This technique allows welding speeds approximately 50% higher than those obtained using a single electrode. It involves the use of two electrodes connected in electrical parallel. A single power source is used, and the two electrodes are often arranged in tandem along the joint. Increase in speed is obtained with this procedure with only a very slight increase in the complexity of equipment. Where the joint fit-up is poor, the two electrodes can be positioned transverse to the joint so that the arcs will strike the edges of the sheet instead of melting deeply into the open groove. The attainable welding speed will not be as high as for a well-fitted joint but will be higher than otherwise attainable.

3. Multiple-Electrode (Multi-Phase Power Supply): Multiple-power tandem welding offers the maximum speeds on material of approximately 0.25 in. and thicker. Speeds will be 2 to 2½ times greater than those obtainable with a single electrode. This technique is generally used for repetitive production welding of long seams; pipe manufacture being an outstanding application. It has not been applied generally to materials thinner than 0.25 in. because of the success obtained with single or parallel electrode welding. In multi-power welding, the two electrodes and the ground lead may be connected to the two-phase output of two Scott-connected transformers, to the output of transformers connected in open-delta or closed delta, or to a combination of a-c and d-c supplies.

These power connections provide control of heat distribution and arc deflection not possible with any other system of multiple-electrode welding.

C. Consumable-Electrode Inert-Arc Welding. Consumable-electrode inert-arc welding provides the advantages of visibility and the absence of flux, either from separately applied granular compositions or the flux from flux-coated electrodes. Visibility has been found important on a great many manual welding installations and on a few special machine welding installations.

D. Tungsten-Arc Inert-Gas Welding. The chief advantage of tungsten-arc inert-gas welding is in welding materials thinner than those which can be welded with the other processes. With it the operator has complete control of metal deposition rate and, often, no filler wire is needed. This process is widely used for making edge welds in material up to $^1/_{16}$ in. in thickness.

Nonferrous Metals

Inert-gas processes have been used almost exclusively for the welding of nonferrous metals. Soon after the tungsten-arc process was first introduced, it served to weld metals such as aluminum, copper, magnesium, nickel and titanium in all thicknesses. Later, the consumable-electrode inert-arc process was introduced, first on aluminum and then for use with the other metals. Initially, it was restricted to the welding of fairly thick sections. However, improvements in wire, power sources and feeding mechanisms have provided many advantages for welding thinner materials. Now, materials as thin as 0.050 in. are commonly welded in production. Welding wires as small as $^1/_{32}$ in. diameter are being fed with good success.

The consumable-electrode inert-arc welding of thin materials is of interest because of the high welding speeds obtainable as compared with tungsten-arc welding. Although it is somewhat more difficult to get welds of equal quality, this process is less expensive than tungsten-arc welding for a great many applications and should get first consideration. However, if the metal is very thin or if full control of filler metal is desired, the tungsten-arc process should undoubtedly be selected.

Stainless Steel

The inert-gas processes are generally selected for the high-speed welding of stainless steel. However, submerged arc welding has also been satisfactorily applied. The selection within the inert-gas group between the tungsten-arc or consumable-electrode process would be

based on considerations similar to those for nonferrous metals.

Joint Design and Orientation

General

Many joint designs are used in welding fabrication. Some are standard, while others reflect the special nature of parts being fabricated. Some of the standard joint designs and features of these joint designs, which are especially pertinent to high-speed welding will be discussed. Edges should always be straight, smooth and clean without excessive shear burs. Joint preparation is particularly important for thin materials and high speeds.

Butt Joint

A. Simple Square-Groove Butt. The simple square-groove butt joint is used extensively for straight seams. With submerged arc welding, the joint should be tightly butted to avoid drop-through. It is necessary to provide a backing bar to prevent drop-through of the weld metal when the joint is not fitted tightly or when full penetration is desired. These conditions apply for submerged arc welding over the complete range of gage thicknesses. For consumable-electrode inert-arc welding, the square-butt joint may be used with metal thickness up to approximately $^{5}/_{32}$ in. A tight fit is used, and for best results a copper backing bar is recommended. However, it is possible to obtain welds with excellent underside contour without a backing bar on thicknesses up to and including $^{2}/_{32}$ in. Gas backing is recommended to achieve these results with the inert-gas processes on carbon and stainless steels.

B. Flanged Edge Joint. The flanged edge joint is especially suited to the tungsten-arc welding process. The flange on many parts may be produced easily by proper shearing procedures. The flange, in effect, provides reinforcement filler metal to the weld, thus obviating the need for filler wire. Furthermore, the upturned edges serve as a guide or attraction to the arc. This provides for good arc direction and minimizes the effect of outside magnetic disturbances.

Lap Joint

The lap joint is used extensively. It is easy to assemble and the parts are easily held in proper contact for welding. Jigging is minimized and, conditions are most suitable for the use of high-speed techniques.

Orientation of Joint

Downhill welding is recommended for maximum welding speeds. By positioning the weldment for downhill welding, the force of gravity can be used to help form the proper weld puddle surface and top speeds can be obtained. Round sections are particularly adaptable to downhill welding. For example, on a submerged-arc application a speed of 175 ipm was obtained with the parts in the flat position. However, when the same weldment was repositioned with the plane of the weld at an angle, welding speeds could be raised to 225 ipm without any sacrifice in weld quality.

Jigging and Fixturing

Proper jigging is a prime requisite for successful high-speed welding of gage materials. Its importance cannot be overemphasized. It is truly "90% of the job." The necessity for accurate jigging increases as welding speeds increase and as material thicknesses become less.

Jigging and fixturing should be thought of as having three main functions:

1. To serve as a production handling device.
2. To hold the work in the proper position for welding.
3. To obtain relative motion between the work and welding head.

Fixtures must be designed to facilitate the production handling of welded parts at a rate commensurate with the speed of welding. For example, consider a 1-min cycle consisting of 15 sec welding time and 45 sec jig time. Should the welding speed be increased from 100 to 150 ipm a 50% increase, the total time would be reduced from 60 to 50 sec, a reduction of only 17%. Where the jigging arrangement allows the welding equipment to operate most of the time, increases in arc travel speed result in almost proportional increases in production. Often, however, welding speeds can be obtained which cannot be fully utilized by the welding fixture and handling facilities. It is then obvious that the faster the jig can be made to operate, the higher will be the actual production rate.

The jig must hold the parts of the weldment rigidly and uniformly together in the relation required for welding. When a backing bar is used to obtain complete penetration, contact of the weldment on the bar must be tight and uniform to avoid melt-through and sticking to the bar.

Very often the work moving or head moving device must be built integrally with the fixture to provide the necessary accuracy in following the seam. It is obvious that the weld bead is deposited where the wire is positioned and that it must be held directly over the seam for uniform results. The accuracy required of the tracing action increases as the material being welded becomes thinner. An error of $^{1}/_{32}$ in. off seam is negligible on 0-gage (0.312-in.) material. On 16-gage material, however, this error is equivalent to 50% of material thickness. This would often produce an unacceptable weld.

Smooth operation of the guiding mechanism is also necessary to obtain smooth weld beads. Nonuniform travel, jerkiness or excessive vibration while the metal is molten, will produce discontinuities of varying degrees in the weld bead. Where process variables have been set up for maximum speed, current will be high and a slight hangup of the guiding device will produce a melt-through or an undesirable blob of metal.

Equipment Requirements for High-Speed Welding

Uniform travel speed and precise control over the position of the wire or electrode are mandatory for

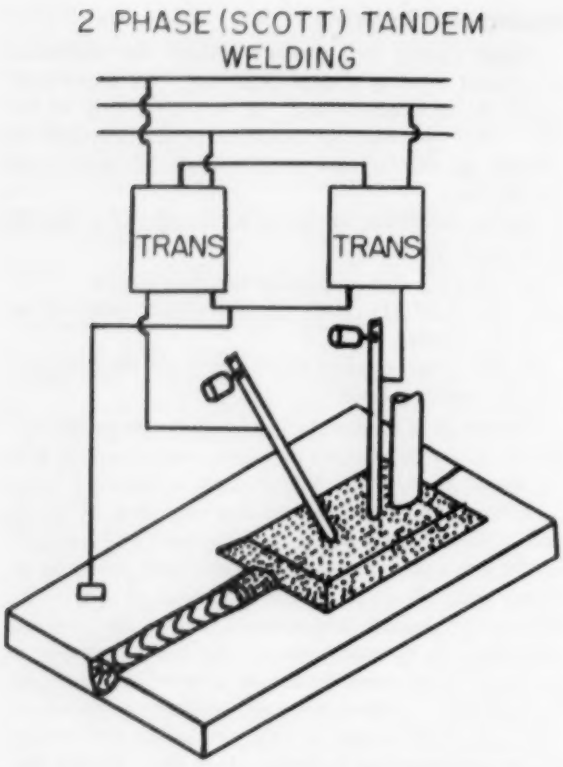


Fig. 3 Submerged arc welding for pipe using a two-phase Scott connection

high-speed welding. The selection of equipment is critical when meeting these requirements.

Electronically governed motors have been widely adopted for high-speed application. These motors provide uniform motion which does not change from time to time with variations in load or temperature. Furthermore, accurate, easily read speed meters provide an easy means for establishing repetitive welding conditions.

In welding, the position of the arc is determined by the position of the end of the electrode. In submerged arc and consumable-electrode inert-arc welding, it is preferable that the welding head straighten the wire. Coiled wire is inherently bent. If, as the bent wire is fed, the orientation of the bend changes, the result may be serious deflections of the arc from the desired path of travel. Therefore, proper wire straightening is desirable though other mechanical means are sometimes used satisfactorily to keep the curvature of the wire in the plane of the seam. The contact nozzle should be positioned so that the wire is as close as possible to the weldment. This will minimize the effect of wire curvature.

Speed of wire feed is critical, regardless of the type of power source employed. With constant-potential welding, constancy of current and metal deposition are directly proportional to the constancy of wire feed. Here, electronically governed motors have proved extremely useful and dependable. When welding with conventional power units, which exhibit the usual drooping characteristics, many control systems can be used. Most are responsive to arc voltage and adjust the wire feed speed to maintain a constant arc voltage. Systems employing electronically controlled motors are undoubtedly the best. With constant-speed electronic governors the perfection of performance achieved by the constant-potential systems is outstanding.

Applications

High-speed welding has potential advantages wherever items made from thin materials are fabricated in production. Illustrations cited here have been selected to show the versatility of present high-speed welding techniques. Furthermore, they have been selected to demonstrate principles of process selection for maximum welding speed.

Figure 3 represents schematically submerged arc welding as applied to pipe, using the two-phase Scott connection. Application of this type of welding to continuous pipe mills produces welding speeds of approximately 85 ipm on $^{5}/_{16}$-in. thick material. Wire sizes of $^{5}/_{32}$ or $^{3}/_{16}$ in. would be used. Normal procedure for full penetration is to use two passes, one inside and one outside, to produce a uniform smooth surface on both sides of the pipe wall.

An interesting combination of single- and multiple-electrode submerged-arc welding is shown in the fabrication of 100-lb propane cylinders. Four separate parts are simultaneously joined by three welds in this application as shown in Fig. 1. The major parts of the two cylinder halves are prepared with a joggle joint and welded with the parallel electrode technique, a close-up of which is shown in Fig. 4. A foot stand is added to one end of the assembly by a continuous lap-fillet weld using a single electrode; a protective cap is added to the other end by an intermittent lap-fillet weld also made with a single electrode. All material is approximately $^{1}/_{8}$ in. thick. These circumferential welds are approximately 48 in. long and are made in 45 sec or approximately 65 ipm. The application of the parallel technique is significant, because without it the speed attained on the end welds could not be maintained on the joggled center joint and still obtain non-porous welds in a single pass.

The high-speed welding application shown in Fig. 5 consists of submerged-arc welding for automobile brake drums. The drums consist of two parts which are formed from 0.094-in. thick steel. The diameter of the wheels at the joint is approximately 9 in. Speeds of 225 ipm were obtained in laboratory tests with the required 70% penetration. To obtain this speed, it was necessary to set the plane of the weld at 35° from the horizontal. The welding wire was positioned to intersect the joint $3^{5}/_{8}$ in. before top center and had a trailing angle of 25°. Welding conditions were ap-

proximately 850 amp DCRP-CP, 27 v using $^5/_{32}$-in. diam wire.

Welds made with the weldment in the flat position were limited to approximately 175 ipm because advantages of downhill welding could not be realized. The wire was positioned 30° trailing. Welding conditions were 550 amp DCRP-CP, 26 v, $^5/_{32}$-in. diam wire.

This application required the accurate process control provided by constant-potential power and the use of a "high-speed" welding composition.

The flat position may be selected for the production application to simplify fixturing, thereby sacrificing the higher speeds obtainable where downhill welding could be applied. Selection of submerged arc welding for this application was based on economics and the attainment of a 100% speed increase over consumable-electrode inert-arc welding in comparative tests.

The refrigerator and compressor housing shown in Fig. 6 is stamped from $^1/_8$-in. thick mild steel. The weld joint is made with the submerged arc process on the flanged edges of the two halves. The flange is approximately $^5/_{16}$ in. high. The shape of the weldment is elliptical, measuring approximately $8^7/_8$ x $10^7/_8$ in. Welds are made at approximately 72 ipm in one pass using 400 amp DCRP, $^1/_8$-in. diam wire. The weld length is approximately 30 in. and over-all time averages 26 sec per unit. The relatively low speed obtained on this particular housing is due to the elliptical shape and the difficulty of following the seam on such a shape. Speeds of over 100 ipm are commonly attained on similar housing having a circular cross section. Submerged arc welding provides a fast, economical method of fabricating compressor housings.

Kitchen sinks are formed from flat sheets by a large hydraulic press. The drawn edges of the sinks are then dressed and a double sink is formed by joining the two sections with a weld as shown in Fig. 7. An older method of oxy-acetylene welding enabled each welder to produce approximately 5 sinks per hour at welding speeds of 3 to 5 ipm. To meet the increasing demand for this product, the manufacturer found it necessary to modernize his production methods and re-evaluate production costs. Submerged arc welding was substituted and gave an increase in production of 25 to 30 sinks per hour—or roughly, a 600% increase over the method formerly used. The 23-in. long welds on the

Fig. 4 Close-up of parallel electrode used for making the girth weld in the propane cylinder shown in Fig. 1

Fig. 5 High-speed application of submerged arc welding to automobile brake drums

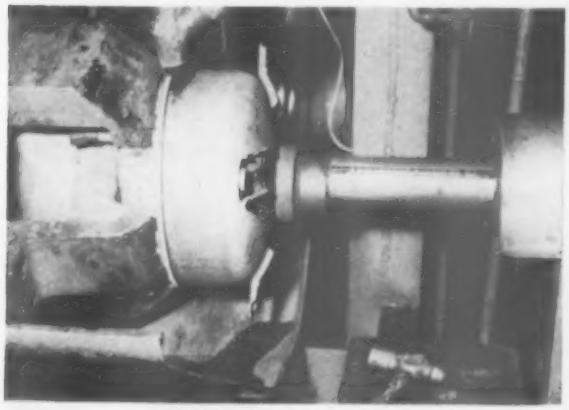


Fig. 6 High-speed welding with the submerged-arc process for the fabrication of refrigerator compressor housings

Fig. 7 Application of high-speed submerged arc welding to the manufacture of kitchen sinks

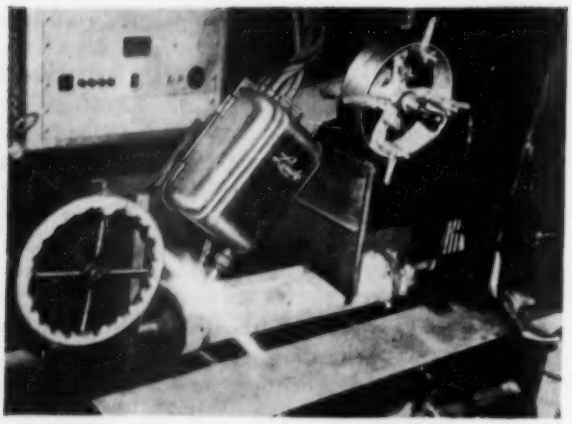


Fig. 8 High-speed application of submerged arc and consumable-electrode inert-arc welding to freon gas condenser tubes

Fig. 9 Completed condenser tube assemblies with fittings installed

Fig. 10 High-speed consumable-electrode inert-arc welding of storage rack made from square steel tubing

14-gage thickness material are made at a speed of 70 to 80 ipm. The welding conditions are approximately 325 to 350 amp at 22 v on $^5/_{64}$-in. diam wire. Constant-potential welding power with the appropriate welding composition produces consistently high quality welds on this application.

The Freon gas condenser tubes pictured in Figs. 8 and 9 are welded by a combination of submerged arc and consumable-electrode inert-arc welding. The condenser tube assembly is formed from 11-gage mild steel, which is rolled into a cylinder and longitudinally welded with the submerged-arc process in a fixture similar to that shown in Fig. 7. Preformed heads are then fitted over each end and tacked in place. The shell is then locked in a lathe type positioner, where a fillet weld is made automatically with a consumable-electrode inert-arc welding machine, as shown in Fig. 8. The best features of both processes were exploited in making these two welds. The economy of submerged arc welding was realized on the longitudinal seam which is made at 30 ipm. The 6-in. diam circular welds were made more easily with the consumable-electrode inert-arc process, because it was not necessary to handle the granular welding composition on the small diameter. Completed assemblies are shown in Fig. 9.

The automobile industry uses pallet type storage racks manufactured from square steel tubing, such as shown in Fig. 10. Tube sections $2^1/_2$ in. square are brake-formed from $^1/_8$-in. thick hot-rolled mild steel. Tube sections range in length from approximately 2 to 7 ft. Production welding was previously done at one plant with flux-coated arc welding, employing five welding operators and one grinder. Production totaled 1300 lineal feet of welding per day. The introduction of manual consumable-electrode inert-arc welding brought about a startling increase in production and a substantial reduction in material costs. This process was selected due to variations in fit-up. Manual guiding was required to compensate for these variations. The open visible arc made it possible to observe the variations in fit-up. In another plant, where a larger expenditure for forming equipment provided better fit-up; mechanized welding was employed.

Figure 10 shows a section of tubing ready for the corner welding operation. The operator uses the pipe in front of him as a support for his forearm. This aids in moving the torch along the joint. An average arc travel speed of 40 ipm has been maintained during production operations. Of every four men originally concerned with this operation three were released for other duties and one man using one consumable-electrode inert-arc welding machine easily did the work. Production immediately jumped to 1500 ft per day, and later to 1800 ft per day. Cost savings served to amortize the equipment in three months.

Another interesting application is the use of the consumable-electrode inert-arc process for fabricating stainless steel tubing consisting of $^3/_8$-in. thick material,

Fig. 11 Application of high-speed consumable-electrode inert-arc welding to the production of stainless steel tubes

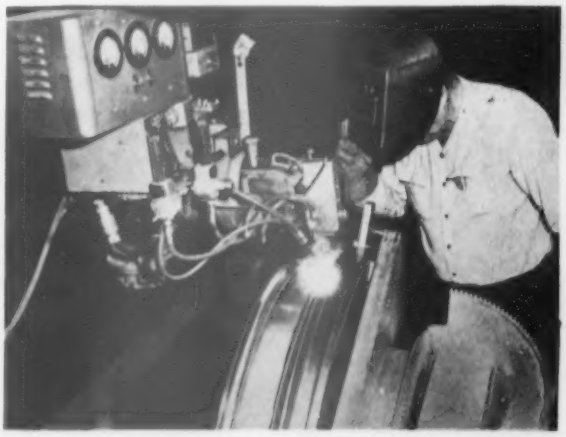


Fig. 12 Application of high-speed consumable-electrode inert-arc welding to the fabrication of stainless steel aircraft parts

approximately 20 ft long. After the tube is formed, it is placed on a planer bed as illustrated in Fig. 11. The installation includes provision for a copper backing bar to shape the inner side of the weld bead. This type of production was formerly done with manual tungsten-arc welding which, a few years ago, had replaced older and very slow methods. Consumable-electrode inert-arc welding increased speed approximately five times over that of tungsten-arc welding. There were obvious savings in consumable materials, and a considerable increase in production occurred. The welding speed is approximately 25 ipm. The use of the consumable-electrode inert-arc welding for this operation has eliminated all interpass cleaning and flux removal. Both were required with the original manual flux-coated arc-welding procedures.

Figure 12 illustrates a part used in the aircraft industry's fabrication of relatively thin stainless steel. This assembly is joined by the consumable-electrode inert-arc process at a welding speed of approximately 60 ipm. A joggled-type lap-fillet weld is used for this joint.

Military rocket cases (see Figs. 13 and 14) are manufactured from relatively thin aluminum. They consist of a central cylindrical body fabricated with a seam weld to which is joined a head on either end. Although a relatively new type of construction, such parts were fabricated during the early part of World War II with mechanized oxy-acetylene welding. This process involved a flux solution, and welding speeds were limited to approximately 80 ipm. The inert-arc processes proved to be unusually suited to the fabrication of this article in large quantities. Consumable-electrode inert-arc welding was selected for the longitudinal seam since a filler metal was definitely required due to somewhat irregular fit-up.

Figure 13 illustrates the machine, which was developed for the production of this part. This mill accepts formed and cut lengths of the tubing. It pushes the shell through the welding station, and forces the edges tightly together. At this point, welding is accomplished at a speed of 200 ipm. No backing is applied to the inside of the seam. The illustration shows a partly welded can emerging from the machine. Electronic equipment maintains the proper wire feed speed as the wire is continuously fed from the coil through the guide and into the welding head.

After welding, these shells are rolled to final dimension and the weld blends into the base metal becoming practically invisible. The problem on the girth welds was found to be somewhat different. Although both the tungsten-arc and consumable-electrode inert-arc processes were developed for use on this joint, the tungsten-arc process was selected. Edge fit-up could be very accurately maintained on this joint. Furthermore, the deposition of fillet weld metal was not required but would present an undesirable weld build-up, which could not be reduced by subsequent rolling. The tungsten-arc process without filled wire served nicely to join these two parts together at a speed of approximately 100 ipm.

The versatility of the process is demonstrated by the

Fig. 13 High-speed machine makes longitudinal seam for aluminum rocket cases by consumable-electrode inert-gas process

fact that the thickness of the aluminum in the head section is approximately twice the thickness of the shell. An expanding backing mandrel is used on the inside to hold and position the parts during welding. Figure 14 shows the parts before welding as well as a completed assembly after welding and rolling operations have been completed. Over a million rocket cases have been produced in this fashion.

The manufacture of aluminum irrigation tubing is another example of the high-speed application of the tungsten-arc process. This tubing is welded continuously from strip cut into lengths, and equipped with end fittings. Production of this tubing is largely mechanical and results in welds such as the enlarged cross section which is shown in Fig. 15. A speed of approximately 25 fpm or 300 ipm is reached during production.

Although not illustrated here, there are two additional applications worthy of mention. One is the use of consumable-electrode inert-arc welding for fabricating hot-water heater tanks. The other is the application of the tungsten-arc process to flanged-butt welding.

The consumable-electrode inert-arc process was used for the high-speed fabrication of welded parts in production of 30 gal hot water heater tanks made of galvanized low-carbon steel. A lap joint was selected for both the head and longitudinal seams, and $^{3}/_{64}$-in. diameter copper welding wire was employed. Flux-coated arc welding was previously tried on this application. It was, however, unsatisfactory since all welds made with this process contained excessive porosity and leaked. A welding speed 68 ipm was obtained for this application.

The noteworthy example of high-speed flanged-butt welding, is the tungsten-arc welded fabrication of a part made of 26-gage Type 410 stainless steel. The flanged joint was used to supply weld reinforcement and to stabilize the arc by providing a raised point to which the arc would naturally be attracted. A speed of over 60 ipm was obtained.

New Developments

Three new developments are beginning to assume more and more importance in the high-speed welding of gage materials. These developments are:

1. Constant-potential power supplies for submerged arc welding and for the consumable-electrode inert-arc process.
2. New granular compositions for submerged arc welding.
3. The use of consumable-electrode inert-arc welding on very thin metals.

Constant-potential power supplies operate, as the name implies, to maintain constant arc voltage, and are inherently superior to electromechanical voltage controls which depend on varying the wire feed rate. Arc voltage is directly proportional to arc length. At the low voltages of 22–24 v required for satisfactory weld contour in light-gage welding, variations that may occur in the short arc length when electromechanical

Fig. 14 The aluminum rocket case is shown before and after welding. The ends are welded to the tube by the tungsten arc process

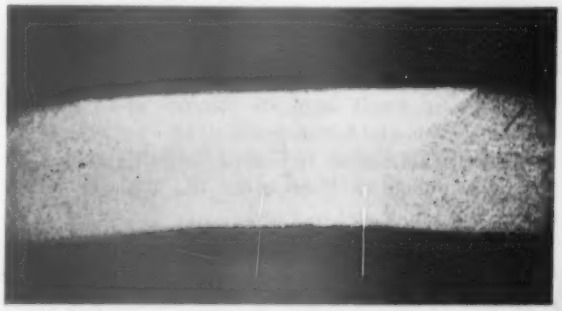


Fig. 15 Micrograph of cross section of weld made in aluminum irrigation tubing produced by high-speed tungsten-arc process

controls are used, can easily result in plunging of the wire. Constant-potential power supplies and constant-speed wire feed eliminate the plunging tendency. In addition, they provide simple current control through wire feed speed and have good starting characteristics.

Welding compositions play an important part in high-speed submerged arc welding. Undercutting is usually the factor which limits welding speed. The speed at which undercutting occurs, varies from one composition to another. With some of the welding compositions, undercut-free welds at speeds of 150 ipm or higher can be obtained in light-gage welding. Special compositions are also available for use with the multi-power techniques on heavier gages, which require considerably higher currents. With improved materials, constant-potential power supplies, and new techniques, the present general speed level of 60–150 ipm will probably be doubled. Such developments are a continuing process, and further improvements may results in still higher welding speeds.

The application of high-speed consumable-electrode inert-arc welding to very thin metals is a striking development. About two years ago, metal approximately $^{3}/_{32}$ in. thick was considered the thinnest material which could be welded with this process. It was welded with wire which had an approximately $^{1}/_{16}$ in. minimum diameter. In response to demands from the aircraft and sheet-metal industries, however, phenomenal achievements have recently been made in the welding of light-gage materials with smaller wires. As a result, it is now possible to use the consumable-electrode inert-arc process on materials, including aluminum as thin as 0.040 in.

WELDED LIGHTWEIGHT STEEL BEAMS FEATURE MASS HOME BUILDING

Increased use of lightweight structural steel in home building may result from its unusual application in a new experimental house (see Fig. 1).

The house, one of six in United States Gypsum Co.'s Research Village at Barrington, Ill., has lightweight beams in all floor and roof areas.

The basic structure of the home at Barrington was designed as rigid frames, spaced on 5-ft modules, and supported by masonry-bearing walls. These rigid frames consisted of 12-in. beams as floor joists, 4- x 4-in. light columns, and 10-in. beams as roof rafters (see Fig 2).

A total of 5831 lb of lightweight beams has been used in the house.

The architects believe that, by shop welding the entire rigid bents, it would be possible in multiple-unit construction to erect the basic structure, including floors and decking, in one working day.

Rigid bents frequently are used to great advantage in industrial construction. This advantage is applicable to homes as well.

Based on a story by the Jones & Laughlin Steel Corp., Pittsburgh, Pa.

The roof of the experimental house had a total design load of 44 psf and the total design load of the floor was 64 psf.

The architects, having decided to use metal-edge plank for the floor and roof-deck construction (see Figs. 3 and 4), specified lightweight beams for the supporting structural units because they are "capable of long spans, are delicate in appearance, and are of sufficient character to become an attractive exposed repetitive element in the architectural composition."

"In general," the architects stated, "steel provided the long spans required in the floor construction of this particular house without excessive weight and apparent mass of the other materials which might have been selected, such as wood or precast concrete."

Beams and columns were fabricated in a job shop. Connections were made with temporary bolts until bents were field-welded into rigid frames.

The architects add: "This experience convinced the general contractor that a better job and a handsome saving could be effected by complete shop welding of the entire rigid frame."

Fig. 1 Lightweight structural steel forms the framework for this experimental house built at the U. S. Gypsum Co.'s Research Village, near Chicago

Fig. 2 Floor joists and roof rafters of experimental house consist of lightweight beams. Note welded connections used in this type of structure

Fig. 3 Workmen are shown as they welded metal edge planking directly to the lightweight steel rafters—a procedure which had never been used in home building before

The metal-edge plank was fastened to the steel by welding the metal reinforcing edge to the top flange of the lightweight beam in such a manner that all welds were concealed. This welded connection, together with the rigid frames, formed a completely rigid structure. This was the first experimental application of metal-edge plank to steel beams by welding.

The use of the lightweight beam in this experimental house has the advantage of a saving in space, both in wall and ceiling construction. In this construction there are no furred ceilings. Consequently the building height may be reduced without psychological loss of space or headroom (see Fig. 5).

Structural steel reduces maintenance requirements both on the exterior and the interior members, and offers fire resistance.

The architects are convinced that the steel structurals in the Research Village house can be shop fabricated completely and erected at the job in conjunction with metal edge deck with enough efficiency in man-hours to effect a handsome saving over conventional methods on a development project of 200 to 300 homes. Rough carpentry has been eliminated from the job. Finished carpentry was limited primarily to the installation of shop-fabricated units in a prefinished building enclosure.

Fig. 4 Another view of welder joining steel edge planking directly to the lightweight steel floor joists

Fig. 5 The lightweight steel beams add a characteristic and attractive note to the experimental house

IMPROVED DESIGN FOR WELDED DRESSER REELS USES AUTOMATIC SUBMERGED ARC

Redesign of textile machinery for welded construction usually implies changing from cast iron to welded steel. Such, however, is not always the case. Once a machine has been designed for steel, frequently further changes can be made to make manufacturing more economical. This design flexibility is one of the advantages of welded design.

The foregoing proved true in the fabrication of large dresser reels or drums used in the textile industry in conjunction with wool spinning frame bobbins or with rewound cones in a magazine creel. They comprise a series of spiders mounted on a shaft, over which is fastened a sheet steel skin. A typical size is 46 in. in diameter and 184 in. long, weighing something over one ton. Operating speed varies, but averages around 113 rpm.

They have always been welded steel assemblies. The previous method of construction was to punch some 300 holes in the 14-gage sheet steel skin, then to make plug welds through them to flanges on the spiders and to tee-iron reinforcing strips located between the spiders. This had to be followed by flush grinding each plug, since the outer surface must be entirely smooth.

At best a rather cumbersome procedure, it has now been revised to include tack welding the tee sections and spider flanges to the inside surface of the skin, then automatically welding the girth and longitudinal skin seams by the submerged-arc method. Tack welds are 1 in. long, spaced 10 in. apart and staggered from one flange to the next.

Based on an award paper in a mechanical design competition sponsored by the James F. Lincoln Arc Welding Foundation.

As shown in Fig. 1, the reel spiders are made up of three sections each —a flange of 4- x $^5/_8$-in. bar stock rolled to the required diameter, a web of $^3/_8$-in. plate flame cut to shape, and a hub sawed from 5-in. round bar stock. These are assembled for tack welding, then checked dimensionally and positioned for automatic welding. A semi-automatic welding head was converted to full automatic operation, Fig 2, by means of a work positioner and rigid mounting for the head. Speed of travel around the flange averages 18 in. per minute and the entire assembly is 100% welded.

Following straightening in a 200-ton press, the spider is stress relieved before mounting on the shaft. Spaced between the spiders are circular $1^1/_2$-in. tee-section steel strips having the primary purpose of supporting the shell on operational loads. They are roll formed in the shape of a helix, after which each complete circle is cut from the helix and left unwelded ready for assembly.

The sheet steel shell is sheared square and cut to length and width, following which a row of "key holes" is laid out for punching. Length is left somewhat on the plus side to compensate for variations developing in rolling to cylindrical shape, in order that the seam or gap at the ends shall not exceed $^1/_{16}$ in. Three of the rolled sheets make up one shell on the 184-in. reel. At one, it will be noted, there is a cone arrangement, formed from 11 gage sheet and welded to the end of the shell. Angle of this cone to the cylindrical section must be held to close limits.

Finished spiders are assembled and keyed to a ground shaft in a floating fixture, shown in Fig. 3. The unit is then checked to insure against sag in the shafting.

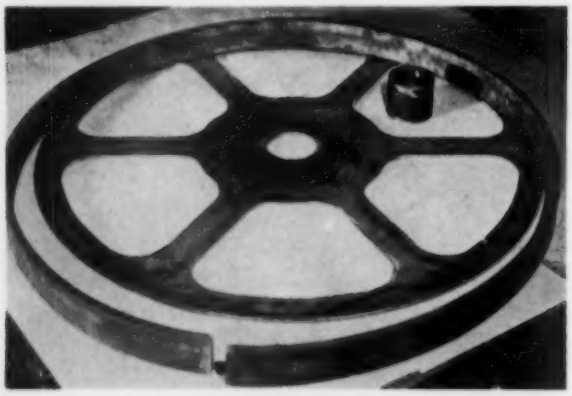


Fig. 1 Rolled flange, flame-cut web plate and hub are 100% welded to make spiders which are tack welded to dresser reel shell; tack welds are 1 in. long and spaced 10 in. apart

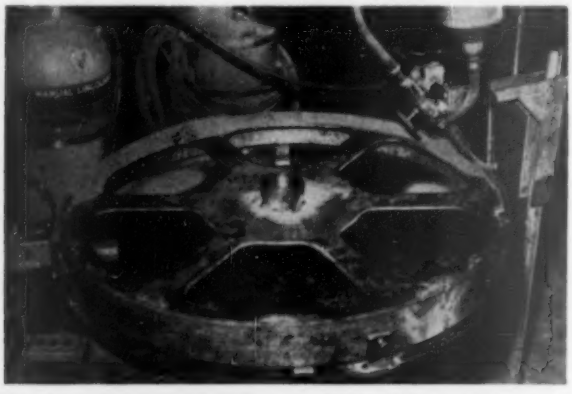


Fig. 2 Three spider sections are tack welded and clamped in a work positioner which moves the flange joint under rigidly mounted semi-automatic submerged-arc welding gun

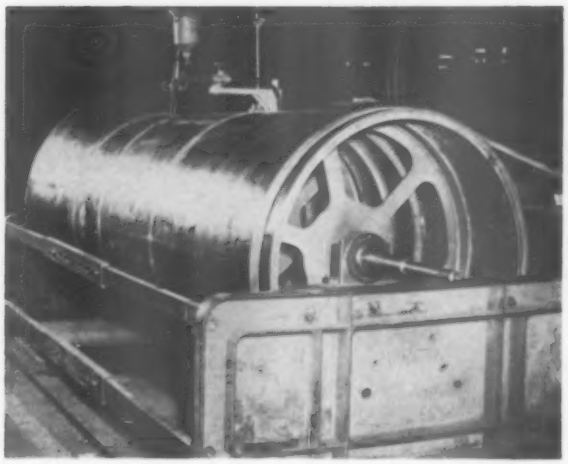


Fig. 3 After tack welding spider flange and intermediate Tee-section supports to the shell, the unit is rotated in a floating fixture under a semi-automatic gun for making girth seams, backed up by the spider flanges

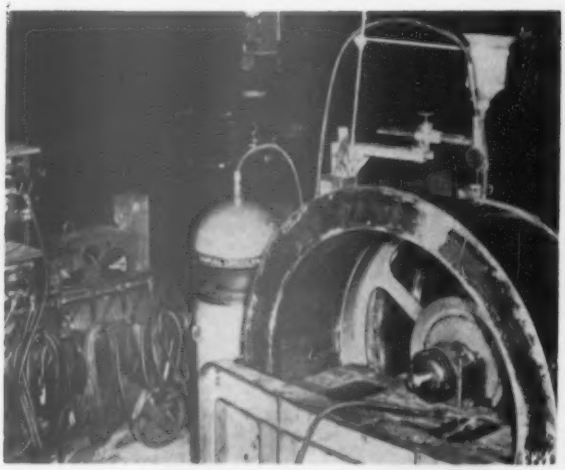


Fig. 4 Semi-automatic unit makes a girth seam at one end where a flared section is joined to the cylinder; longitudinal shell seams are also made by this unit moving on an overhead track

The skin sections then are rolled onto the spiders, one at a time, a further check on shaft alignment being made before each sheet is tack welded to the spiders and tee sections.

Automatic submerged-arc welding is used to complete the seams in the shell members. As illustrated in Fig. 4, the welding head is a straight tube arrangement mounted in a conventional burning torch through which the electrode wire is fed. Attached to one side is a flux storage hopper. This entire unit is rigid and the cylinder is rotated under it by means of a gear reduction unit and belt.

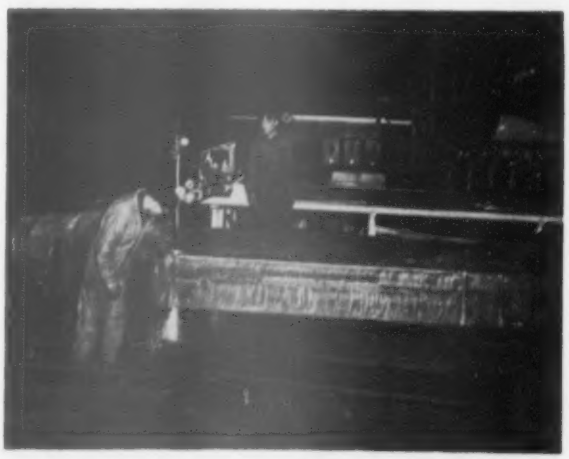
Each girt seam is continuously welded its entire length and is backed up by a spider flange, preventing burn-through. Longitudinal seams are welded in similar fashion, using the same equipment mounted on a carriage running on a track for the length of the cylinder. Total length of all welds per cylinder is 246 ft.

Final operations include grinding all welds smooth and flush, along with removing burrs before a final dimensional check. A typical inspection shows a runout on the face of the spider hub of only 0.017 in; on the brake ID area 0.002 in.; average on the OD of the cylinder cone section 0.090 in. and on the OD of the main shaft at either extreme end 0.0025 in.

FLAME-CUTTING RUSHES FORGED SLABS FOR ATOMIC PROGRAM

The oxy-acetylene flame-cutting machine shown in the accompanying illustration had easy going as it sliced an 18 x 108- x 65-in. section out of a king-sized carbon steel forging at the Isaacson Iron Works, Seattle, Wash. The rectangular-shaped slab was one of several in a rush order for the Hanford Atomic Energy Plant. It took less than 2 hr to make a total linear cut of 336 in. on each of the slabs, through the 18-in. depth. A templet tracer guided the cutting action.

Based on a story by the Linde Air Products Co., New York, N. Y.



Flame cutting of 18- x 108- x 65-in. section out of larger carbon steel forging

70,000 SQUARE FEET OF DOME

Inert-gas metal-arc welding plays important role in building fabulous semisphere

BY JOHN LUND

Fig. 1 Inert-gas metal-arc welding process being used to weld parts of Semisphere Building. Inert-gas metal-arc welding joins aluminum plates to proper shape for concentric tiers. Fast welding of structural aluminum speeds production

John Lund is District Manager of Air Reduction Sales Co., Shreveport, La.

Whether the Semisphere Building of R. G. LeTourneau, Inc., was inspired by the pleasure-dome decreed by Kubla Khan in Xanadu, we don't know—but out of the wide reaches of Texas has come a spectacularly new dome-shaped building in gleaming aluminum.

Twelve thousand people can be seated in this spacious structure designed for such purposes as commercial and civic entertainment and religious gatherings. It can also be used for manufacturing and assembly line operations and merchandise warehouses. Rising 85 ft high, the Semisphere Building has a circumference of 942 ft. Most unusual of all—none of the workers who erected the building left the ground.

The way this construction feat was achieved reminds you of erecting the "big top." First, a center column of steel was erected and a sliding collar attached to it. Next, a circle of concave aluminum sheets was bolted to the ring and the whole business hoisted into the air.

After that, a second row of sheets was attached to the first. As still more rows were bolted into place in concentric circles, all of them were hoisted from the ground until they formed a tent-like dome suspended in the air. Then it was lowered gently to a foundation ring of concrete where the bottom edge of the building was firmly secured.

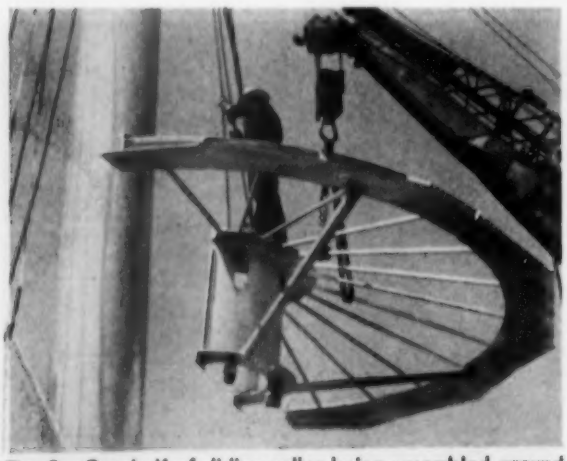


Fig. 2 One-half of sliding collar being assembled around center pole. As sheets are bolted on, electric winch raises structure

Fig. 3 Welds in aluminum sheets show type of production work performed by inert-gas metal-arc welding process

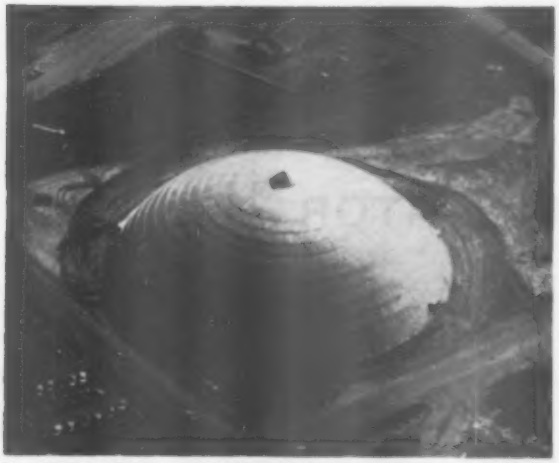


Fig. 4 Aerial view of Semisphere Building adjacent to R. G. Le Tourneau plant at Longview, Tex.

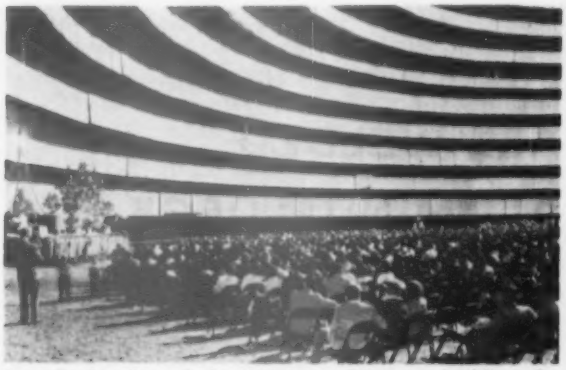


Fig. 5 Interior of Semisphere. Spacious building for auditorium, warehouse, manufacturing, big displays, athletic events. Can seat 12,000 people

Such a revolutionary approach to construction called upon the application of all the most modern techniques, among which the inert-gas metal-arc welding process played an important part. To produce the concentric circular tiers, the aluminum plates forming the upper rings were trimmed on an angle and the wedge-shaped pieces re-inserted—just like putting in gores to make a circular skirt. Only, instead of a sewing machine, the inert-gas metal-arc welding process was used to weld them into solid plates.

Speed and simplification also followed from the use of inert-gas metal-arc welding—over 184 seams were welded representing about 2300 lineal feet, and the time required was only about 100 hr. Smooth finish, strength and efficiency all dictated the use of inert-gas metal-arc welding in this unique structural work.

WELDING OF TITANIUM UNDER PLASTIC TENT LEADS TO BETTER WELDS

An interesting technique for the fusion welding of titanium has been developed at the Des Moines, Iowa, plant of Solar Aircraft Co.

In a molten state titanium absorbs many gases—such as oxygen, nitrogen and hydrogen—that tend to make welds in the metal brittle. Therefore fusion welding of titanium is usually done in a "controlled atmosphere"—by keeping air away from the weld, and by bathing the work with an inert gas.

In welding sizable titanium aircraft components at Solar, it was found desirable to make a gastight zippered plastic tent (shown in the accompanying photo). The tent is fastened to a standard welding table. The operator wears long-sleeved rubber gloves, sealed to the vinyl bag, to gain freedom of movement. Inside the plastic tent the atomosphere can be carefully controlled for perfect welds.

Welding of titanium in gas-tight plastic tent

ALL-WELDED ALUMINUM DECK-EDGE ELEVATOR

A huge deck-edge elevator recently completed by the Puget Sound Naval Shipyard for the Navy's new carrier, the *Shangri-La*, is the largest all-aluminum, all-welded structure in America, and possibly in the entire world. This 87,000-lb. elevator, shown in Figs. 1 to 3, quickly shifts a plane from the flight deck on top of the carrier to the hangar deck below, or vice versa. It will be installed on the port side and will act as a continuation of the vessel's canted deck when in the raised position.

The use of high-tensile aluminum resulted in important savings over steel. The new elevators have an equal capacity to previous elevators with a saving of 17 tons in weight. This weight saving occurs high on the side of the vessel where such savings really mean something. All welding was done by the inert-gas metal-arc welding process.

This all-welded structure represents an important achievement because it demonstrates that even the toughest problems of shrinkage and alignment can be solved. Subassemblies were constructed as large as possible. Then extensive tests were made to determine proper welding sequence for best heat control throughout the complicated structure.

The elevator is essentially a cantilever structure composed of a series of transverse and longitudinal trusses covered with longitudinal I-beams and a thin skin of aluminum and surfaced with wood to form the flight deck. Two sets of rollers run in vertical tracks to provide the movement required.

Based on a story by the Reynolds Metals Co., Louisville, Ky.

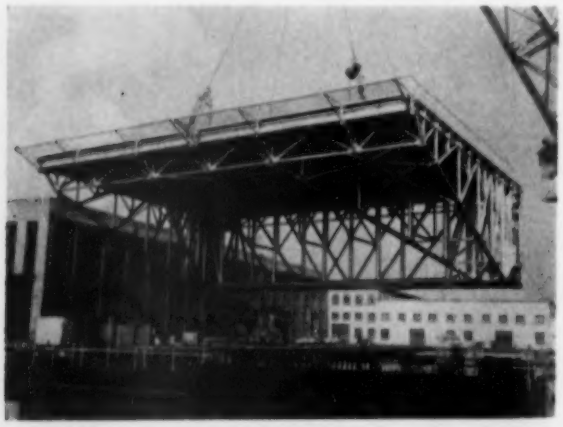


Fig. 1 Huge deck-edge elevator for the Navy's new aircraft carrier, the *Shangri-La*, is claimed to be largest all-aluminum, all-welded structure of its type in the world

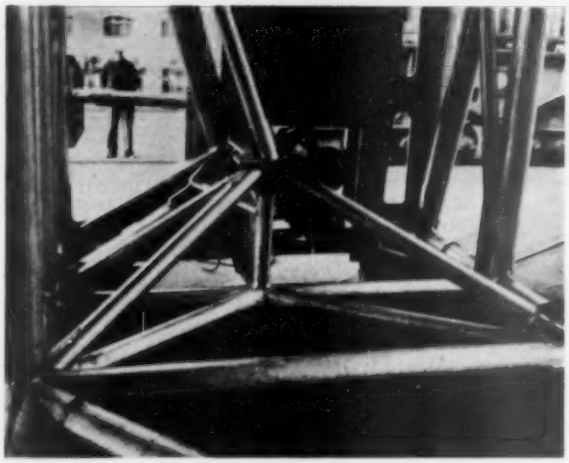


Fig. 2 Special techniques were developed to overcome the expansion and contraction problems in welding the heavily reinforced structure. Note how great strength is obtained by multiple-triangular bracing employed throughout in constructing this deck-edge elevator

The close-up of a typical joint shows that as many as nine pieces of tubing are welded together at a single point. These clusters are reinforced by splice plates, carefully designed and positioned to distribute the working loads lengthwise a portion of each tube. In

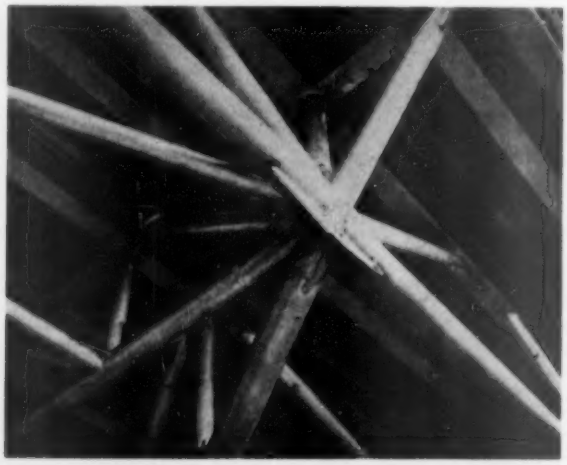


Fig. 3 Note how tube clusters are reinforced with splice plates to distribute working loads lengthwise over a portion of each tube. Avoiding load concentration at tube ends in this manner greatly increased over-all efficiency of the structure

WELDING ARCS NEWS

this manner, all the forces are not concentrated at the tube ends, in turn greatly increasing loading factors and over-all efficiency of the structure.

The success of this highly engineered structure is a tribute to the quality of workmanship achieved at the Puget Sound Naval Shipyard. Fitting up the multiple joints involved an exceedingly high level of craftsmanship as did the actual welding itself.

The elevator for the *Shangri-La* is the first of twelve or more such elevators planned for other carriers.

PRODUCTION OF CONTROL LEVERS SIMPLIFIED BY STUD WELDING

Stud welding helps DeWalt Inc., Lancaster, Pa., to realize cost savings of 5% in the building of three of the most-used controls on its "Power Shop" (see Fig. 1). These savings are brought about by assembling component parts of the controls with a standard stud welding gun mounted vertically on a yoke fixture bolted to a table (see Fig. 2). The split-second end-welding operation, requiring only one man, contrasts with the former practice of hand welding the components together, then hand grinding and machining them—a procedure involving several workers. Moreover, stud welding leaves no blemishes or machining marks that have to be removed.

The machine's elevating handle, which is rotated to raise or lower the motorized arm, is formed by welding a special $^3/_8$-in. bent stud to a round collar. The collar fits over the elevating shaft and is jointed to it with a solid cotter pin.

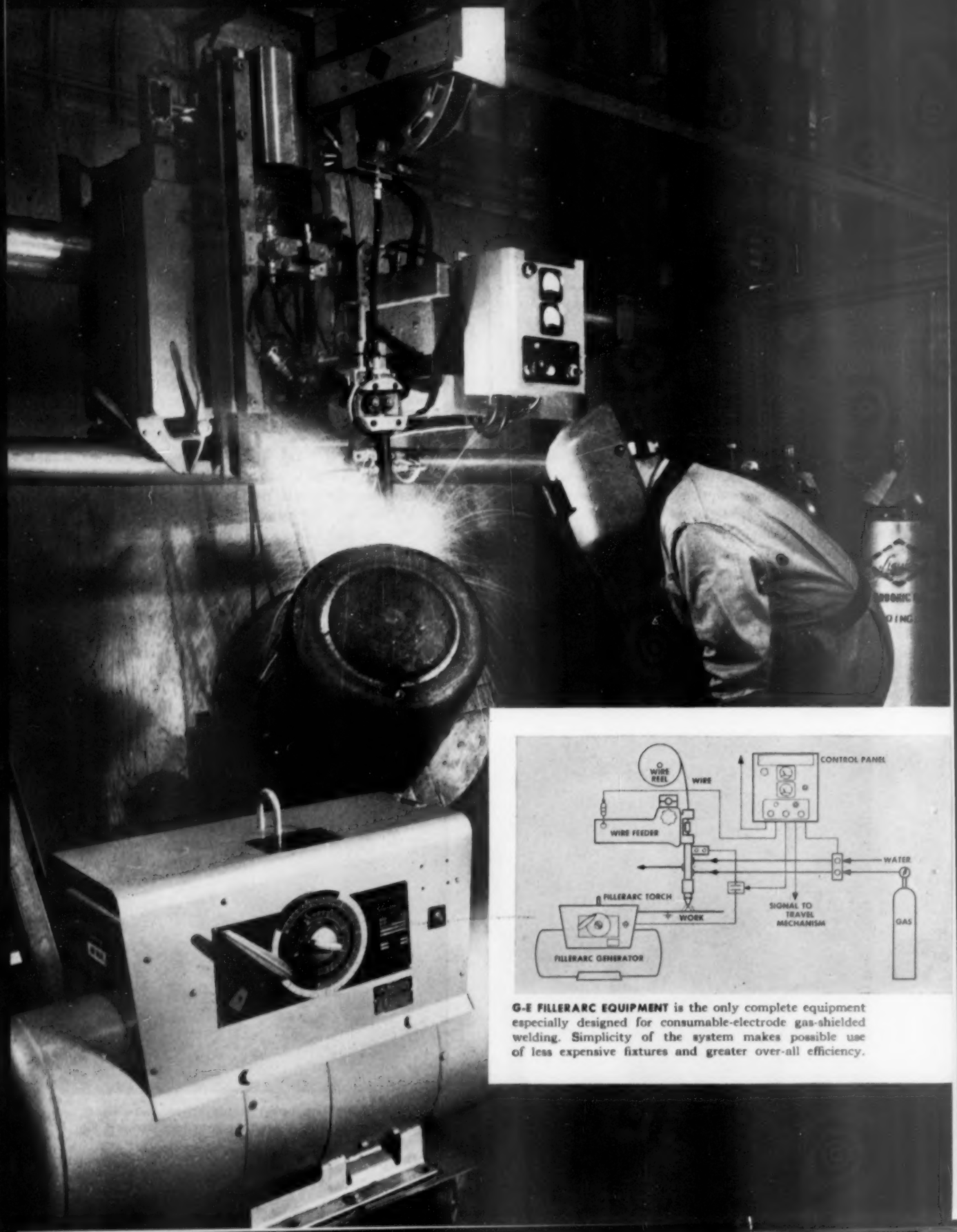
Similarly, a straight no-thread $^3/_8$-in. stud is welded to a hexagonal collar to form the handle that locks or releases the motor yoke at any point of its 360-deg horizontal swivel. The third end-welded control is the rip lock, a $^3/_8$- x 2-in. special stud with national fine threads and a special rivet end, which is welded to a knurled handle. By being turned against the machine arm, the rip lock holds the yoke in place at any point of travel along the arm.

During stud welding, special holding fixtures position the studs and other components. The gun is actuated by an air cylinder. Efficiency of the operation is further increased by bringing bins full of studs and the other components to the table, where they are within easy reach of the seated operator (see Fig 2). After welding, assemblies are placed in a caster-mounted truck, also close at hand.

Based on a story by the Nelson Stud Welding Division, Gregory Industries, Lorain, Ohio.

Fig. 1 Fabrication of the four control levers for this power tool has been simplified by stud welding

Fig. 2 Stud welding being employed to assemble three of the most-used controls on the power tool shown in Fig. 1



G-E FILLERARC EQUIPMENT is the only complete equipment especially designed for consumable-electrode gas-shielded welding. Simplicity of the system makes possible use of less expensive fixtures and greater over-all efficiency.

NEW G-E Automatic Welding System Uses CO_2 to Slash Gas Costs 95%

FILLERARC . . . first *complete* equipment designed especially for automatic gas-shielded welding; combines unique generator with low-cost carbon dioxide—for sound welds on mild steel.

General Electric's new Fillerarc Automatic Welding Equipment brings you—not only 95% savings in shielding-gas costs—but *sound welds on mild steel.* The great savings possible through use of CO_2 as a shielding agent have long been recognized—but good mild steel weld quality has never been obtained. Now, after two years of successful application of Fillerarc equipment on non-ferrous metals (using inert gas), G-E engineers bring you the total solution for mild steel welding—*savings plus high quality.*

95% SAVINGS ARE POSSIBLE because CO_2 costs only *1/20th* as much as inert gas. For the average job, Argon would cost $5.00 per hour, CO_2 only twenty-five cents. This means yearly savings per equipment may be as high as $20,000 on a 3-shift, 60% duty cycle basis. This new G-E system can now replace the submerged arc method on many jobs and eliminate many of the problems associated with granular flux.

EXCLUSIVE G-E GENERATOR practically eliminates the erratic weld quality formerly obtained with CO_2. Here's why: Only the G-E Fillerarc generator—with its exclusive *rising* volt-ampere characteristic—supplies an arc length which always remains constant, even with adjustments in wire speeds. This means minimum weld porosity and spatter—and deep penetration for extra-strong welds.

COMPARED TO OTHER INERT-GAS SYSTEMS, G-E Fillerarc equipment . . .

- Reduces gas costs 95%, for yearly savings up to $20,000 per equipment;
- Delivers consistent weld quality because of the unique G-E Fillerarc generator;
- Assures constant speed; system is insensitive to normal line-voltage changes;
- Provides wire-feed speeds as high as 1000 I.P.M.

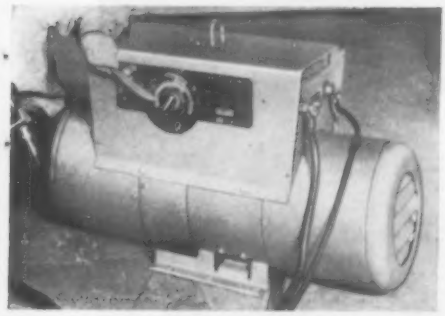
COMPARED TO FLUX-SHIELDED METHODS, G-E automatic Fillerarc equipment . . .

- Deepens penetration with low-cost CO_2;
- Provides a visible arc for full control of weld quality, permits less expensive fixtures;
- Does not use abrasive flux—especially important in welding compressor housings and similar jobs;
- Eliminates stubborn flux slag; cleaning costs are greatly reduced;
- Eliminates expensive flux recovery systems.

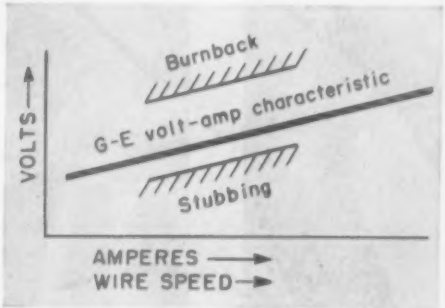
FOR MORE DATA contact your G-E welding sales engineer—and write for bulletin GEC-1334 to Section 713-1, General Electric Co., Schenectady, N. Y.

SEE G-E automatic Fillerarc equipment demonstrated at the National Metal Exposition, Philadelphia, October 17–21.

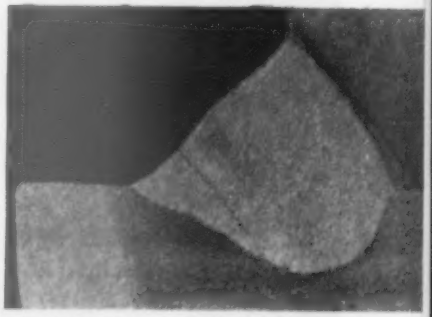
Why the complete G-E system makes possible quality mild-steel welds with CO_2



G-E SELF-REGULATING GENERATOR is the heart of the Fillerarc Automatic Welding system. Unique rising volt-amp curve maintains constant arc length.



RISING VOLT-AMP CURVE of the exclusive G-E Fillerarc generator matches rising arc curves . . . does not get into area of burnback and stubbing. Resulting high weld quality is uniform.



DEEP PENETRATION is produced by short arcs and faster wire speeds tpyical with Fillerarc equipment. Above: weld on semi-killed steel.

Progress Is Our Most Important Product

GENERAL ELECTRIC

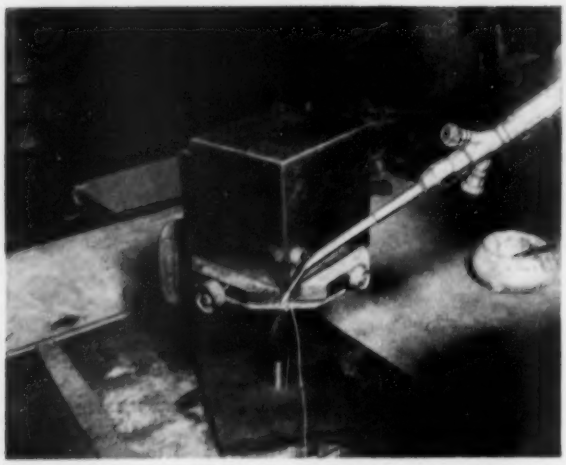


Fig. 1 After being placed in a special jig, the sides of this brass instrument box are tack-welded

Fig. 2 The tack-welded box is then placed in this jig to make the soldering operation easier

SILVER SOLDERING PROVIDES PRESSURE-TIGHT JOINTS

BY R. M. WALTERS

Instrument boxes for aircraft must meet the standards for flight conditions. One instrument manufacturer makes a brass box that must have pressure-tight seams since one-half of the box is filled with an inert gas. Special care must be taken when the joints of this box are soldered. The following procedure is used to insure pressure-tight seams when the instrument box is in use.

The sides of the box are first tack-welded, and the partly assembled box is placed in an aligning jig (see Figs. 1 and 2). After the tack-welded box is positioned securely, an expandable liner is inserted into it, but not tightened (see Fig. 3). Pieces of silver-solder wire are bent to conform to the shape of the inside corners and carefully inserted into the box so that they lie along the joints. Then the expandable liner is tightened, forcing the silver solder into the correct position along the seams. The outside of the joint is heated with an oxy-acetylene torch, melting the silver solder (see Fig. 4). A strong, nonporous joint is formed as the solder flows into the space at each corner box.

When the soldering operation is completed, the liner is removed, and the joints are filed and smoothed with emery paper and steel wool.

R. M. Walters is associated with the Linde Air Products Co., Baltimore, Md.

Fig. 3 The silver-solder wire is inserted along each corner joint, and the expandable liner is tightened to securely position the wire

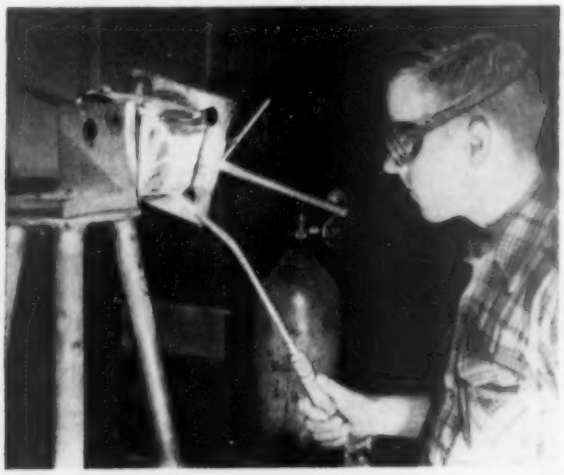
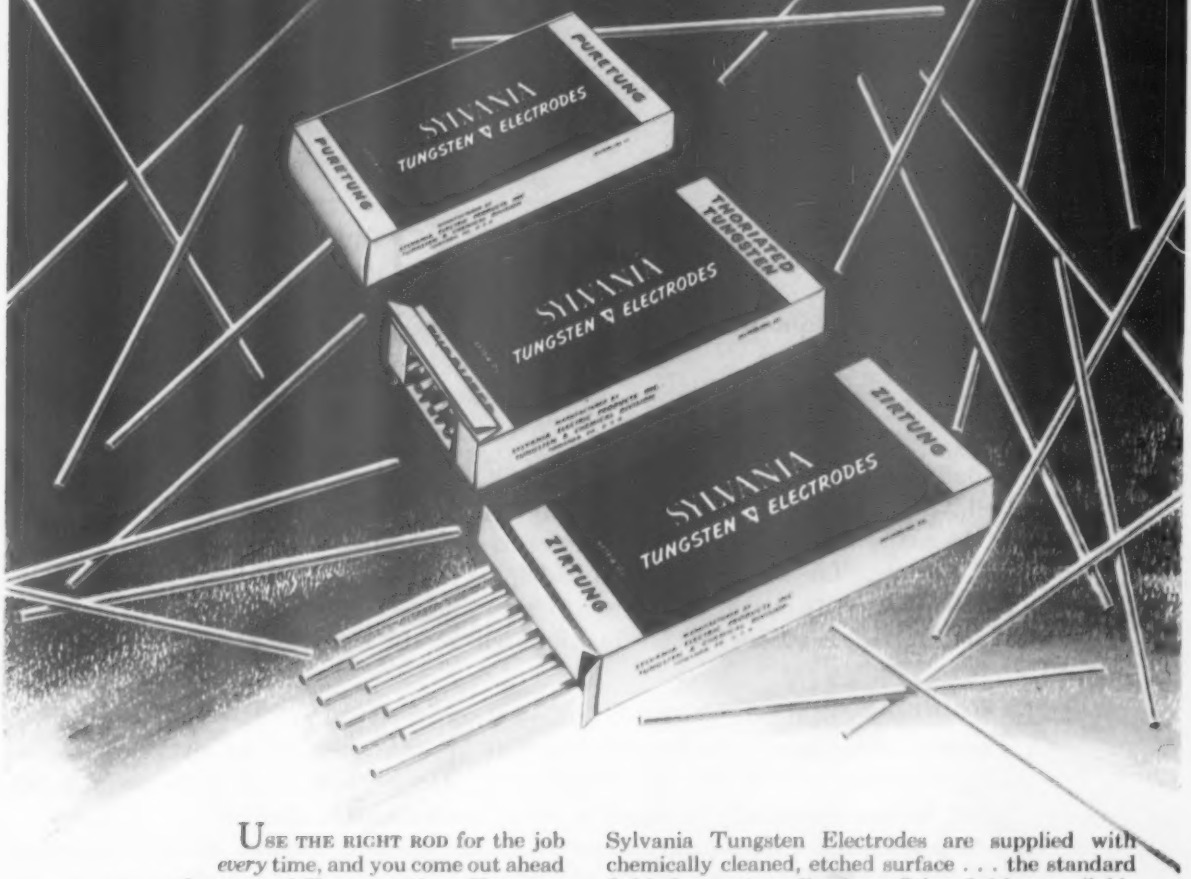


Fig. 4 Heat is applied to the seams of the instrument box, and the solder forms a pressure-tight joint; then, the expandable liner is removed

Inert Gas Welding?

Standardize on Sylvania Tungsten Electrodes for dependability, ease of handling, economy...



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Sylvania Tungsten Electrodes are supplied with chemically cleaned, etched surface . . . the standard finish for most applications. Other finishes available include centerless ground.

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Society News

TECHNICAL PAPERS SESSIONS

1955 NATIONAL FALL MEETING

OCTOBER 17–21

BELLEVUE-STRATFORD HOTEL, PHILADELPHIA, PA.

AWS REGISTRATION

Pergola—18th floor

Sunday, Oct. 16
3:00 P.M. to 6:00 P.M.
Monday, Oct. 17
8:00 A.M. to 4:00 P.M.
Tuesday, Oct. 18
8:00 A.M. to 4:00 P.M.
Wednesday, Oct. 19
8:30 A.M. to 4:00 P.M.
Thursday, Oct. 20
8:30 A.M. to 3:00 P.M.
Friday, Oct. 21
8:30 A.M. to 12:30 P.M.

Philadelphia, "City of Brotherly Love," will be the scene this month of the National Fall Meeting. Over 1200 AWS members are expected to attend and participate in the many activities planned for the five-day meeting from October 17 through October 21. The hard-working Philadelphia Section, who are handling all the detail arrangements for the meeting, will act as hosts. Headquarters hotel and location of the meetings and social functions will be the Bellevue-Stratford Hotel.

TECHNICAL ACTIVITIES

Twenty-one technical sessions are planned at which a total of sixty-two papers will be presented. Practically all phases of welding activity will be covered and latest developments will be reported on by authorities in the field.

As has been the custom in former years, the opening session, Monday morning, will be devoted to presentation of awards for achievement and service to the welding industry and the Society. Highlight of the session will be the Adams Lecture which is to be delivered by LaMotte Grover of the Air Reduction Sales Co. His talk will be "An Interpretation of Research and Experience in Structural Welding."

Another technical feature will be the educational lecture series which this year will cover "Mechanical Properties of Steel Weld Metals."

PLANT TOURS

Two plant tours which should have wide appeal have been arranged. On Wednesday morning, members taking the tours will visit the U. S. Naval Shipyard and witness many different welding operations being used on ship repairs and conversion work. On Thursday morning, Baldwin-Lima-Hamilton Corp., Eddystone Div., will be visited. Here welding, fabrication, machining and erection of locomotives, turbines and testing machines will be observed.

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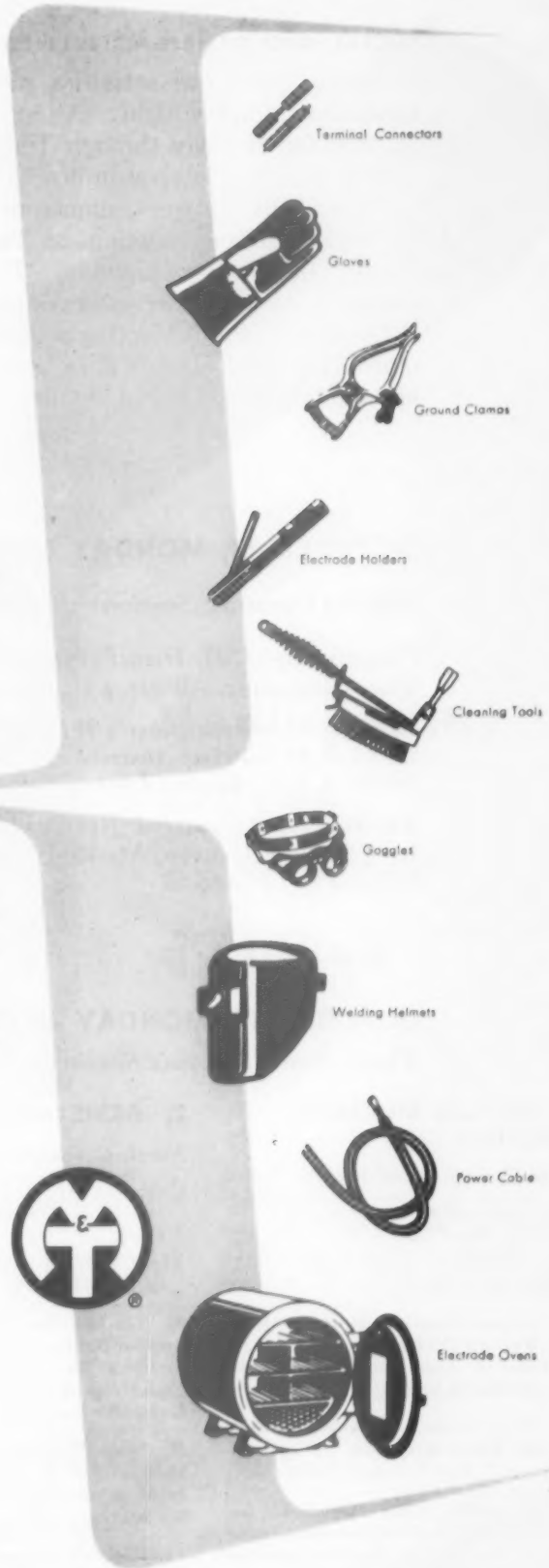
For a copy of the M & T accessories catalog contact your nearest M & T branch office, or write.



METAL & THERMIT CORPORATION • WELDING DEPARTMENT • 100 EAST 42ND STREET, NEW YORK 17, N. Y.

SOCIAL AND OTHER ACTIVITIES

Featuring the social activities will be the President's Reception and National Dinner on Monday night. An interesting ladies entertainment program has been planned for Monday through Thursday, including a luncheon on Tuesday and a visit to points of interest in nearby Bucks County.

Throughout the week, numerous committee meetings will be held. There will be Section Officers' meetings on Tuesday and Wednesday mornings and a general business meeting on Thursday. The annual Welding Research Council University Conference and Dinner will take place on Wednesday evening.

Details of all Fall Meeting activities are listed in the accompanying pages. The official Program which will be given members and guests when they register will also contain full and final details.

OCTOBER 17, MONDAY MORNING

Official Opening Session—10:00 A.M.—Rose Garden

Chairman—*J. H. Humberstone, President, American Welding Society*
Vice-Chairman—*Walter Goerg, Jr., Chairman, Convention Committee*

10:00 A.M.—President's Welcoming Address
10:15 A.M.—Prize Awards
10:30 A.M.—Adams Lecture

An Interpretation of Research and Experience in Structural Welding by LaMotte Grover, Air Reduction Sales Co.

OCTOBER 17, MONDAY AFTERNOON

Three Simultaneous Sessions

1. CO_2 GAS SHIELDED WELDING

Rose Garden—2:00 P.M.

Chairman—S. B. Owings
Miller Elec. Mfg. Co.
Vice-Chairman—John Lang
Lukens Steel Co.

A. Carbon-Dioxide Shielded-Metal Arc-Welding Process
by Robert J. Keller and John P. Koss, A. O. Smith Corp.

B. Moisture and Its Effects in Carbon Dioxide Welding of Steel
by Roger W. Tuthill, General Electric Co.

C. Electrode Characteristics for Welding Mild Steel in Atmospheres of Carbon Dioxide by the Consumable-Electrode Gas-Shielded Welding Process
by Robert D. Mann and Julian D. Carey, General Electric Co.

2. RESISTANCE WELDING

North Garden—2:00 P.M.

Chairman—T. E. Jones
Precision Welder & Flexopress Corp.
Vice-Chairman—Oscar Fredericks
General Electric Co.

A. The Behavior of Spot-Weld Cross-Section During Loading
by John F. Rudy, Wright Air Development Center, Roy B. McCauley and Robert S. Green, Ohio State University

B. Seam Welding Dissimilar Thicknesses of Low-Carbon Steel
by M. L. Begeman and Ernest J. Funk, University of Texas

C. Resistance Spot-Welding Schedules for Welding Projection Hardware to Mild Steel Sheet and Plate
by O. K. Barnes, Westinghouse Electric Corp.

3. WELDABILITY AND RESEARCH

South Garden—2:00 P.M.

Chairman—W. D. Doty
U. S. Steel Corp.
Vice-Chairman—John H. Gross
Lehigh University

A. Effect of Preheating on Stress-Corrosion Cracking of Steel Weldments
by E. Paul DeGarmo and I. Cornet, University of California

B. Heat Treatment of Air Hardening Alloys on Welding
by John J. B. Rutherford and John F. Ewing, Babcock & Wilcox Co.

C. The Development of High-Tensile High-Impact Electrodes
by G. S. Wepfer, A. O. Smith Corp.

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OCTOBER 18, TUESDAY MORNING

Three Simultaneous Sessions

4. WELDABILITY AND RESEARCH

South Garden—9:30 A.M.

Chairman—WALTER WOODING
U. S. Naval Shipyard
Vice-Chairman—R. D. STOUT
Lehigh University

A. Further Studies of the Hot Ductility of High-Temperature Alloys
by Ernest F. Nippes and Warren F. Savage, Rensselaer Polytechnic Institute

B. Lattice Structure Dependence of Weld Stress Ductility-Temperature Relationships
by Julius Heuschkel, Westinghouse Electric Corp.

C. A Test Block for Welding Gray and Nodular Cast Irons
by W. A. Schumbacker and A. L. Schaeffler, Allis-Chalmers Manufacturing Co.

5. STRUCTURES

North Garden—9:30 A.M.

Chairman—VAN RENSSELAER P. SAXE
Vice-Chairman—HARRY BRINKMAN
Phoenix Bridge Co.

A. Fatigue Strength of Welds in Low-Alloy Structural Steels
by G. E. Nordmark, W. H. Munse, J. E. Stallmeyer and N. M. Newmark, University of Illinois

B. Welding of Structural Steel for Hartford Library
by Carl L. Kreidler, Lehigh Structural Steel Co.

C. Fabrication of Crosshead Beams for the World's Largest Hydraulic Press
by V. M. Nigriny, The Midvale Co.

6. INSPECTION AND TESTING

Rose Garden—9:30 A.M.

Chairman—R. W. CLARK
General Electric Co.
Vice-Chairman—SAMUEL BAUM
Philadelphia Navy Yard

A. Backing Ring Elimination Permits Ultrasonic Testing and Avoids Cracking of Piping Welds
by Wilfred A. Pollock, Wisconsin Electric Power Co.

B. The Gamma Radiographic Control of Welded Transmission Pipe Lines
by Colin M. C. Bates, Welding Supervision Ltd.

C. Radiography in the Jungles of Sumatra, Indonesia
by Walter W. Offner, X-ray Engineering Co.

OCTOBER 18, TUESDAY AFTERNOON

Three Simultaneous Sessions

7. WELDABILITY AND RESEARCH

South Garden—2:00 P.M.

Chairman—L. C. BIBBER
U. S. Steel Corp.
Vice-Chairman—J. HEUSCHKEL
Westinghouse Electric Corp.

A. The Effect of Microstructure on Notch Toughness and Fracture Morphology—Part II
by Joseph C. Danko, John H. Gross and Robert D. Stout, Lehigh University

B. Crack Arresting by Overlays of Notch Tough Weld Metal
by P. P. Puzak and W. S. Pellini, Naval Research Laboratory

C. Studies on the Brittle Failure of Tankage Steel Plates
by F. J. Feely, Jr., M. S. Northup, and Stanley Kleppe, Esso Research & Eng. Co., M. Gensamer, Columbia University

8. SHIPBUILDING

Rose Garden—2:00 P.M.

Chairman—A. A. HOLZBAUR
Sun Shipbuilding & Drydock Co.
Vice-Chairman—R. S. BRADWAY
N. Y. Shipbuilding Corp.

A. Offshore Drilling Barges
by Robert H. Macy, The Ingalls Shipbuilding Corp.

B. All-Welded 96-Ft American-Built Motor Yacht
by LaMotte Grover, Air Reduction Co., and E. H. Holder, Ingalls Shipbuilding Corp.

C. Stress Studies of Various Shaped Welded Doublers in Hatch Corner
by Yoshio Akita, Transportation Technical Research Institute of Japan, H. Kihara, University of Tokyo, N. Ando, Transportation Technical Research Institute, and K. Yoshimoto, Ishikawajima Heavy Industry Co.

9. WELDING EQUIPMENT

North Garden—2:00 P.M.

Chairman—C. I. MACGUFFIE
General Electric Co.
Vice-Chairman—FRANK IAPALUCCI
Baldwin-Lima-Hamilton Corp.

A. Characteristics of a Rectifier Type Constant Voltage Power Supply
by Jesse W. Pomazal, Harnischfeger Corp.

B. Transient Problems With High-Flux Density Transformers in Welding Applications
by Robert C. Mierendorf, Square D Co.

C. Evaluation of Power Supplies for Inert-Gas Metal-Arc Welding
by A. Lesnewich and Everett Cushman, Air Reduction Co., Inc.

Originators not Imitators

"Every kind of imitation speaks the person that imitates as inferior to him whom he imitates, as the copy is to the original."

LORD SOUTH

R. D. WASSERMAN

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A FEW "EUTECTIC" FIRSTS
1940-1955

- U.S. Patent #2,583,163. Surface alloying process for bonding metals.
- U.S. Patent #2,288,669. First Torch Alloy for joining cast iron with color match, without fusion.
- U. S. Patents #2,359,813, #2,410,850, #2,544,000. First metallic film coating to enhance Surface Alloying.
- U. S. Patents #2,279,282, #2,279,283, #2,279,284. First nickel bearing copper alloy for high tensile joining.
- U.S. Patent #2,481,053. First torch alloy and flux for joining high aluminum content metals.
- U.S. Patent #2,471,803. First "Low Amp" coating for metal arc welding of cast iron.
- U.S. Patent #2,632,000. First low-melting electrode for high tensile strength joining of aluminum.
- U.S. Patent #2,632,835. First "Low Amp" electrode coating for high alloy steels.
- U.S. Patent #2,626,339. First electrode for high tensile strength joining of copper.

RESEARCH—BACKBONE OF PROGRESS

During the past 50 years Eutectic Welding Alloys Corporation has learned much. It is possible for imitators to analyze our welding rods, electrodes and fluxes. But originating and producing them is an achievement only "Eutectic" can claim. Only the long, hard road of doing it can provide the answers.

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President, Founder, Director of Research

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OCTOBER 19, WEDNESDAY MORNING

Three Simultaneous Sessions

10. STAINLESS STEELS

South Garden—9:30 A.M.

Chairman—G. E. LINNERT
Armco Steel Corp.
Vice-Chairman—R. K. LEE
Alloy Rods Co.

A. Mechanical Properties of Modified Type 347 Weld Metals
compiled by K. Poole and R. D. Thomas, Jr., Arcos Corp., for the AEC Advisory Committee on Stainless Steels

B. Hot Cracking of Stainless Steel Weldments
by P. P. Puzak, W. R. Apblett and W. S. Pellini, Naval Research Laboratory

C. Permeability and Crack Senstivity of Stainless Welds
by John L. Lang and Charles Wright, Jr., Lukens Steel Co.

11. WELDING ELECTRODES

Rose Garden—9:30 A.M.

Chairman—ERNEST FRANKS
Philadelphia Testing Laboratory
Vice-Chairman—D. L. MATHIAS
Arcrods Corp.

A. Metal Powder Electrodes and Their Applications
by E. DiLiberti, Air Reduction Sales Co.

B. Properties and Applications of Low-Hydrogen Iron Powder Electrodes
by D. C. Smith, W. G. Rinehart and D. C. Helton, Harnischfeger Corp.

C. Effect of Individual Coating Ingredients on Surface Tension of Iron Electrodes
by Thomas H. Hazlett and Earl R. Parker, University of California

12. APPLICATIONS

North Garden—9:30 A.M.

Chairman—D. B. HOWARD
A. C. F. Industries
Vice-Chairman—RUDI A. GUENZEL
Southern Oxygen Co.

A. High-Speed Welding of Steel Compressor Cases
by C. F. Stephenson, York Gramly Division of York Corp., and Robert A. Stone, Air Reduction Sales Co.

B. New Surfacing Techniques
by K. H. Koopman and R. S. Zuchowski, Linde Air Products Co.

OCTOBER 19, WEDNESDAY AFTERNOON

Three Simultaneous Sessions

13. TITANIUM & MOLYBDENUM

South Garden—2:00 P.M.

Chairman—W. L. WARNER
Watertown Arsenal
Vice-Chairman—A. S. ROSE
I-T-E Circuit Breaker Co.

A. Welding of Titanium
by E. F. Gorman, Linde Air Products Co.

B. Resistance Welding Ductile Joints in Commercially Pure Titanium
by Robert Wickham, Marquardt Aircraft Co.

C. Effects of Oxygen on Soundness and Ductility of Molybdenum Welds
by W. N. Platte, Westinghouse Electric Corp.

14. WELDING ELECTRODES

Rose Garden—2:00 P.M.

Chairman—R. D. THOMAS, JR.
Arcos Corp.
Vice-Chairman—G. E. CLAUSSEN
Metals Research Laboratory

A. A New Approach to Welding of Alloy Steels with Alloy Fluxes
by Emmett Smith and Paul Jerabek, The Lincoln Electric Co.

B. Gas Shielded Consumable Electrode Welding of 4130 Steel
by Craig R. Sibley, Air Reduction Co., Inc.

C. Effect of Current and Atmospheres on Arc Temperatures
by George M. Gordon, Olga A. Colter and Earl R. Parker, University of California

15. PRESSURE VESSELS

North Garden—2:00 P.M.

Chairman—F. L. PLUMMER
Hammond Iron Works
Vice-Chairman—CHARLES DOOLEY
Sun Shipbuilding & Drydock Co.

A. Performance of High-Strength Pressure Vessel Steels
by J. H. Gross and R. D. Stout, Lehigh University

B. Resistance of Low-Alloy Steel Plates to Biaxial Fatigue
by C. E. Bowman and T. J. Dolan, University of Illinois

C. The Practical Approach to the Welding of Stainless Steel Pressure Vessels
by Frederick H. Clash, Jr., Link-Belt Co.

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OCTOBER 20, THURSDAY MORNING

Three Simultaneous Sessions

16. ALUMINUM

Rose Garden—9:30 A.M.

Chairman—WALTER MEHL
Heintz Mfg. Co.
Vice-Chairman—W. R. APBLETT
Foster Wheeler Corp.

A. Inert Shielding Gases for Welding Aluminum
by James D. Dowd, Aluminum Company of America

B. Hydrogen vs. Acetylene vs. Inert Gas in Welding Aluminum Alloys
by J. Koziarski, Piasecki Helicopter Corp.

C. Welding Aluminum to Copper Using Inert-Gas Metal-Arc Process
by L. A. Cook and M. F. Stavish, Kaiser Aluminum & Chemical Corp.

17. PIPING & PRESSURE VESSELS

North Garden—9:30 A.M.

Chairman—JAMES GLEASON
United Engineers & Constructors
Vice-Chairman—H. J. IRRGANG
W. K. Mitchell Co.

A. Welding of High-Temperature High-Pressure Piping with Chrome-Moly Electrodes
by Loyd D. Nesbitt, Metal & Thermit Corp.

B. The Application of Inert-Gas Tungsten-Arc Welding to Carbon Steel Pipe
by F. J. Pilia and R. W. Minga, Linde Air Products Co.

C. How to Weld High Pressure Vessels with Automatics
by Wilmer W. Weber, The Pfaudler Co.

18. APPLICATIONS

South Garden—9:30 A.M.

Chairman—G. R. PEASE
International Nickel Co., Inc.
Vice-Chairman—A. M. GARCIA
Morris Wheeler & Co.

A. Automation of Metal Manufacturing Requires Correct Use of Arc Welding
by H. O. Klinke, The Taylor-Winfield Corp.

B. Submerged Arc Welding Methods and Their Applications
by Robert Wilson, The Lincoln Electric Co.

C. Lower Part Cost by Projection Welding
by C. H. Burgston, Deere & Co.

CCTOBER 21, FRIDAY MORNING

Three Simultaneous Sessions

19. BRAZING

North Garden—9:30 A.M.

Chairman—A. N. KUGLER
Air Reduction Sales Co.
Vice-Chairman—F. W. HUSSEY
Pitman-Dun Laboratory

A. Wettability of Steel with Pure Silver and Silver Brazing Alloys
by Nikolajs Bredzs, Armour Research Foundation of Illinois Institute of Technology

B. Physical Properties of Butt Joints Brazed with BCu, BAg-1, and BAg-3 Filler Metals
by Grant Hansel, Jr., Materials & Processes Laboratory, General Electric Co.

C. Mechanized Brazing of Fan Components
by Frank G. Leuthner, Sawyer-Bailey Corp.

20. MAINTENANCE & PRODUCTION

South Garden—9:30 A.M.

Chairman—R. S. BABCOCK
Linde Air Products Co.
Vice-Chairman—ROBERT BENWELL
Yale & Towne Mfg. Co.

A. Effective Welding Circuit Maintenance
by Donald L. Caldwell, Caterpillar Tractor Co.

B. Inert-Arc Consumable-Electrode Welding for Automobile Rear-Axle Housings
by E. G. Lommel, Chevrolet Division, General Motors Corp.

C. Contour Beveling with the Electronic Tracer
by Howard B. Cary, Marion Power Shovel Co., and R. F. Helmkamp, Air Reduction Sales Co.

21. APPLICATIONS

Rose Garden—9:30 A.M.

Chairman—J. MIKULAK
Worthington Corp.
Vice-Chairman—H. V. INSKEEP
Linde Air Products Co.

A. How to Use Steel Effectively in Machinery
by Omer Blodgett, The Lincoln Electric Co.

B. An Application of Pressure Welding to Fabricate Continuous Welded Rail
by D. C. Hastings, Richmond, Fredericksburg and Potomac Railroad Co.

C. Manual Arc Welding of Butt Joints in Crane Rails
by Ivan Kuluchief, A. O Smith Corp.

EDUCATIONAL LECTURE SERIES

South Garden

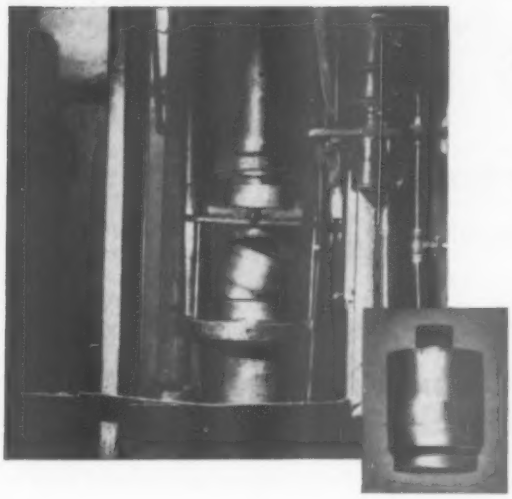
TUESDAY, OCTOBER 18, 4:30 TO 6:00 P.M.

WEDNESDAY, OCTOBER 19, 4:30 TO 6:00 P.M.

Chairman: ***DR. H. UDIN, Massachusetts Institute of Technology***

"Mechanical Properties of Steel Weld Metals," by Julius Heuschkel, Westinghouse Electric Corp.

Look How You Save by Hard-Facing

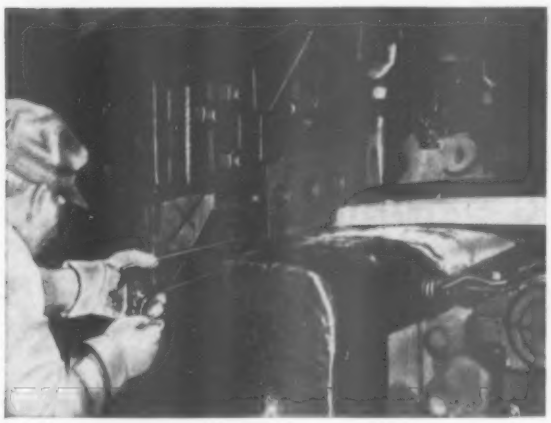


PRODUCTION LIFE INCREASED 1000%

This hard-faced punch mandrel has produced 10,000 pipe couplings and still shows no sign of losing gage. Unprotected tool steel mandrels wore out after punching only 1000 pieces, and case-hardened mandrels punched only 500 pieces before they had to be replaced. A 3/16-in. layer of HAYNES STELLITE hard-facing alloy protects the mandrel from wear and galling.

SAVES $4000 PLUS

Rebuilding this worn extrusion screw with HAYNES STELLITE alloy No. 1 cost $2000—$4000 less than a new screw would cost. And the rebuilt screw will give from 4 to 6 times more service than a new, unfaced screw. The screw is used to extrude rubber from a solid to a semi-liquid state. Wear is the chief problem, and it is effectively resisted by the hard-faced surfaces.



SHEAR 4 TIMES THE TONNAGE

These hard-faced blades shear an average of 200 tons of tough alloy billets. This is more than 4 times the average for special steel blades. Hard-facing with HASTELLOY alloy C protects the blades from wear, and they keep a keener cutting edge longer. When the blades finally do wear, they can be hard-faced again at a fraction of their replacement cost.

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Sales Offices
Chicago — Cleveland — Detroit — Houston
Los Angeles — New York — San Francisco — Tulsa

OTHER ACTIVITIES

OCTOBER 17, MONDAY EVENING

6:00 P.M.—President's Reception—Burgundy Room

8:00 P.M.—National Dinner—Rose Garden

OCTOBER 19, WEDNESDAY MORNING

10:00 A.M.—Manufacturers Meeting—Green Room

OCTOBER 19, WEDNESDAY AFTERNOON AND EVENING

2:00 P.M. to 3:00 P.M.—Business Meeting—Junior Room

6:30 P.M.—WRC University Dinner—Red Room

8:00 P.M.—WRC University Conference—Junior Room

OCTOBER 20, THURSDAY MORNING

10:00 A.M.—Board of Directors' Meeting—Green Room

12:30 P.M.—Sustaining Member Luncheon—Junior Room

WELDING AND CUTTING EXHIBITS AND DEMONSTRATIONS NATIONAL METALS EXPOSITION

Convention Halls
Philadelphia, Pa.

Hours of the Exposition

Monday, October 17	*12 Noon to 10:30 P.M.*
Tuesday, October 18	*12 Noon to 10:30 P.M.*
Wednesday, October 19	*12 Noon to 10:30 P.M.*
Thursday, October 20	*10:00 A.M. to 6:00 P.M.*
Friday, October 21	*10:00 A.M. to 6:00 P.M.*

Admission by special invitation or by AWS registration badge or membership card of any participating society.

PLANT VISITS

The U. S. Naval Shipyard, Naval Base, Philadelphia, Pa., and the Baldwin-Lima-Hamilton Corp., Eddystone Division, Philadelphia, Pa., have been selected as plants for visitation. Both tours will leave the Bellevue-Stratford Hotel at 9:00 A.M. and return by 12:30 P.M. Herewith is a résumé on what may be seen at these plants.

On Wednesday morning, October 17, 1955, the U. S. Shipyard plans to show the visitors through the Structural Shop where ship structural assemblies of both steel and aluminum alloy are fabricated. The manual, submerged and inert-gas metal-arc welding processes will be observed. Welding operations on a ship undergoing repair, overhaul or conversion in a drydock will be viewed. In addition, a tour through a submarine will be scheduled. If time limitations preclude each person visiting all the facilities and ships noted above, the tour will be organized in three groups, the visitor giving his preference before entering the Shipyard. A guide will be provided for each fifteen visitors.

Citizens of the United States require no clearance. Foreigners must have clearance from the Navy Department through their attachés in Washington. Visitors will not be permitted to take cameras into the Base nor will they be allowed to take notes or make sketches.

Thursday morning, October 18, 1955, visitors may observe the following at the Baldwin-Lima-Hamilton Corporation:

1. Diesel Engines—Welding, Fabrication, Machining and Erection.
2. Steam Locomotives—Welding, Fabrication and Erection.
3. Flex Plates—Fabricated from Carilloy T-1 Steels for Wind Tunnels at Arnold Engineering Center, Tullahoma, Tenn.
4. The fabrication of 300 foot-tubes, 35 feet in diameter, for the vehicular tunnel at Hampton Roads, Va. This project is especially interesting. Unusually large fixtures for fabrication of the sections comprising these tubes have been developed. Method of launching these tubes is radically different from conventional launching methods.
5. The Propeller Shop will be included in the tour. Of special interest here will be propellers made of Nialite, the remarkable alloy that has been setting record service performance as compared to other alloys used in the casting of propellers.
6. Fabrication and assembly of structural steel for the New Jersey Turnpike Extension Bridge.
7. Fabrication and assembly of dump cars and hopper cars.
8. Very heavy turbine weldments, which combine hot forming to critical curvatures, flame cutting and welding, etc., for the Corps of Engineers, U. S. Army-Dalles Dam Project.
9. Machining and assembly of Universal testing machines, powdered metal compacting presses and hydraulic presses for forming metal parts.
10. Machining of gigantic hydraulic turbine wheels, shafts and the heavy weldments which comprise many of the sub-assemblies for turbine installations.
11. Manufacture of SR-4 Strain Gauges, as well as a visit to the Metal Powder Experimental and Testing Laboratory.

LADIES' ENTERTAINMENT

MONDAY THROUGH THURSDAY

Registration 9:00 A.M. to 4:00 P.M. in Gold Room, first floor, Bellevue-Stratford Hotel.

Coffee Hour (except Monday), 10:00 A.M. at the Hotel in Pink Room, first floor.

MONDAY

Luncheon at hotel

President's Reception and Annual Dinner will be held in the evening.

TUESDAY

Luncheon, cards and prizes at the Llanerch Country Club.

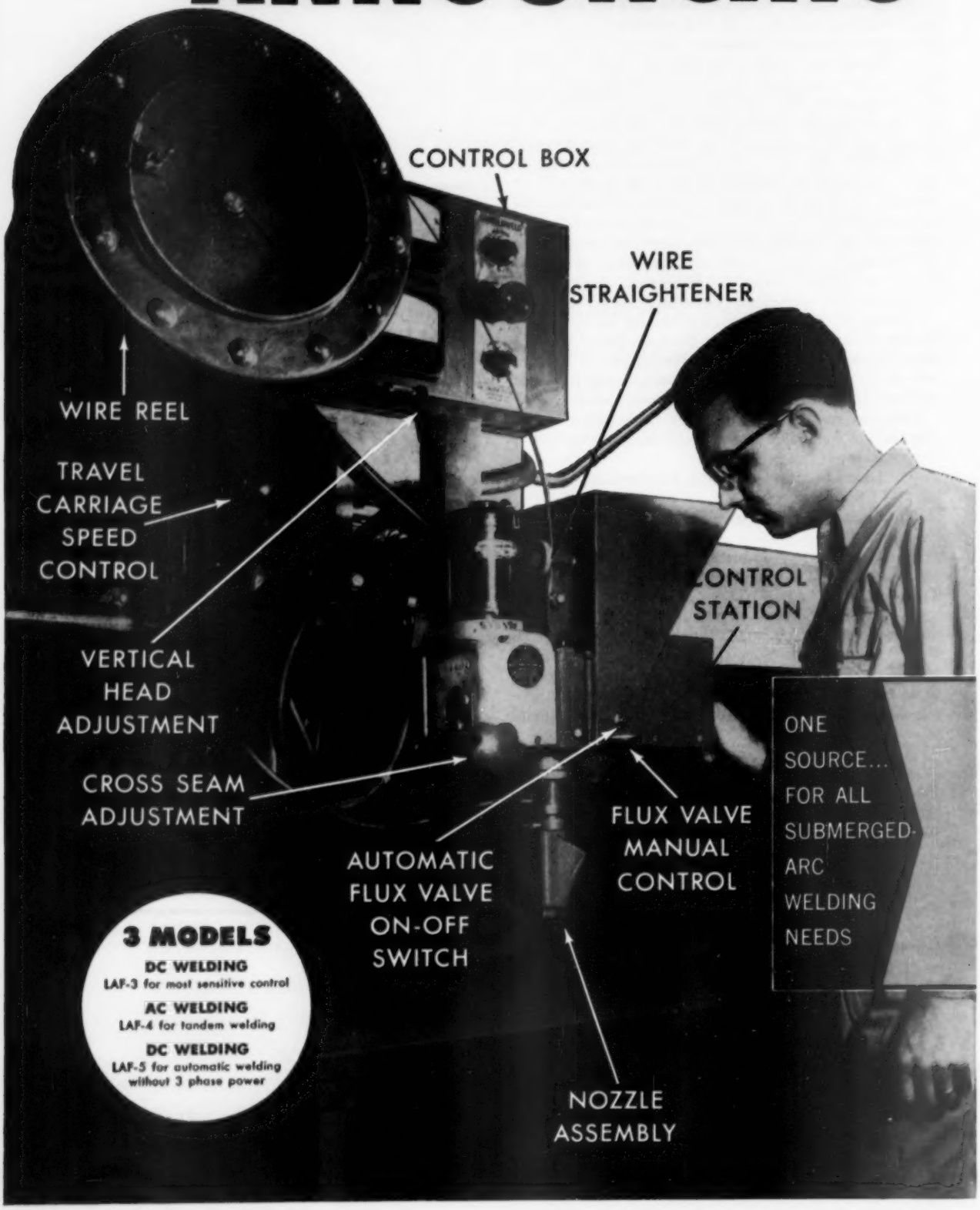
WEDNESDAY

Tour to Bucks County, Washington's Crossing, Luncheon, lecture and sightseeing.

THURSDAY

Luncheon at Cherry Hill Inn. Lecture on antiques.

ANNOUNCING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FLUX VALVE MANUAL CONTROL
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ONE SOURCE... FOR ALL SUBMERGED-ARC WELDING NEEDS
3 MODELS
DC WELDING
LAF-3 for most sensitive control
AC WELDING
LAF-4 for tandem welding
DC WELDING
LAF-5 for automatic welding without 3 phase power

A NEW LINE

of automatic WELDERS and POWER SOURCES for submerged-arc welding

LINCOLNWELD now gives you

- AC or DC welding current
- Motor-generator or rectifier for DC welding
- Variable voltage or constant potential generator

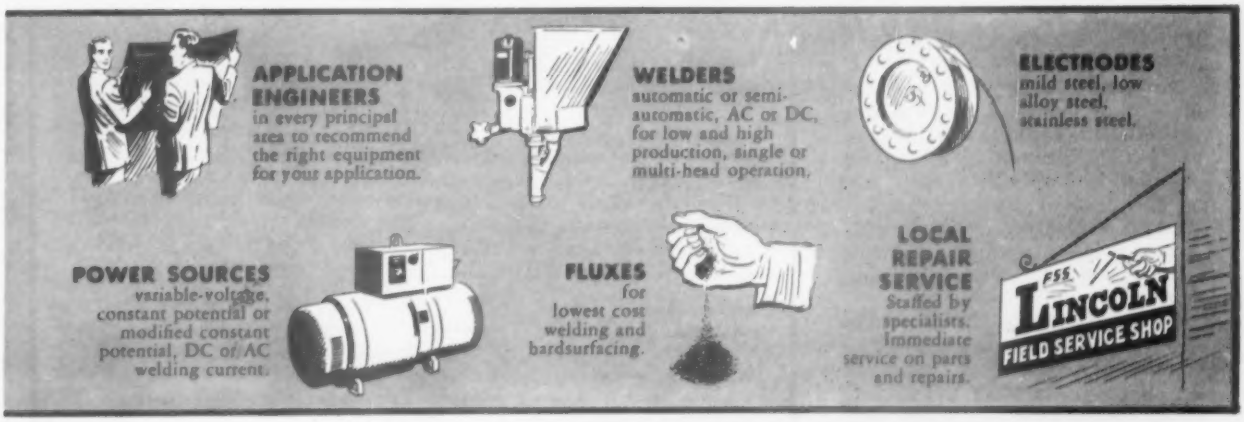
PLUS

Choice of Cold Starts or Hot Starts

Choice of Stand-still Start or Flying Start

Variable inching speed to or away from work

Automatic flux control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in every principal area to recommend the right equipment for your application.
WELDERS
automatic or semi-automatic, AC or DC, for low and high production, single or multi-head operation.
ELECTRODES
mild steel, low alloy steel, stainless steel.
POWER SOURCES
variable-voltage, constant potential or modified constant potential, DC or AC welding current.
FLUXES
for lowest cost welding and hardsurfacing.
LOCAL REPAIR SERVICE
Staffed by specialists. Immediate service on parts and repairs.
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FIELD SERVICE SHOP

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Write for Bulletin 1355 giving complete facts.

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The World's Largest Manufacturer of Arc Welding Equipment

Mechanical Properties of Weldments

The AFS-AWS Joint Committee on Welding Iron Castings invites data or test reports upon the mechanical properties of gray iron weldments. Welds made with different filler metals are eligible. Manufacturers of welding rod or casting consumers who have made tests of this type are invited to submit their data to the chairman of the Mechanical Properties of Weldments Subcommittee, Mr. Sidney Low, Chapman Valve Manufacturing Co., Indian Orchard, Mass. If so desired, the source of information will be treated as confidential and not revealed.

The committee would also welcome any other data on welding iron castings such as test methods, metallography, etc.

Barker Nominated by ASME

Joseph W. Barker, chairman and president of the Research Corp., New York City, has been nominated to serve as next president of The American Society of Mechanical Engineers.

Mr. Barker will take office at the Society's annual meeting in Chicago this fall, after letter-ballot approval of ASME's 40,000 members.

Mr. Barker, a native of Lawrence, Mass., was graduated in 1916 from Massachusetts Institute of Technology, to which he returned as an associate professor in 1925. He became head of the electrical engineering department at Lehigh University in 1929, and dean of engineering at Columbia University in 1930, a post he held until 1946.

During World War II, Mr. Barker served as a special assistant to the Secretary of the Navy, being responsible for all naval education and training policy, including the V-12 college training program.

Mr. Barker will continue in his post as head of Research Corp., a nonprofit foundation established to make grants-in-aid for scientific research, particularly to smaller colleges and universities. He is also chairman of the board of the corporation's wholly owned subsidiary, Research-Cottrell, Inc., and current president of The Society of The Sigma Xi, national scientific association.

TAC TALKS

Safe Practices for Inert-Gas Metal-Arc Welding

by H. F. Reinhard

As is often the case with new processes or materials, the general adoption of inert-gas metal-arc welding by industry has raised some questions concerning potential hazards with its use. While other welding processes have been adequately covered in American Standard Z49.1, "Safety in Electric and Gas Welding and Cutting Operations," this standard was issued prior to the use of inert-gas metal-arc welding, hence this process is not included.

A special Subcommittee of the AWS Committee on Safety Recommendations has devoted much time and effort in preparing recommended safe practices for this welding process, which have recently been released as a printed pamphlet.

In preparing the recommendations the Subcommittee reviewed existing literature, reviewed industrial records, investigated reports of complaints and made supplementary studies. Only those potential hazards which were peculiar to, or might be increased by, the inert-gas metal-arc process were considered. Inert gas in this case was considered to include only helium or argon, mixtures of helium and argon or mixtures of argon with oxygen.

Potential hazards considered of sufficient importance to be included in the investigation were: ozone, oxides of nitrogen and those gases resulting from trichlorethylene decomposition; also radiant energy, radioactivity from thoriated-tungsten electrodes and metal fumes. Where considered necessary, adequate control measures are recommended.

The report is based on findings to date. New data will be considered when available. Comments and reports of experience will be most welcome. Address all communications to: Secretary, Committee on Safety Recommendations, American Welding Society, 33 West 39th St., New York 18, N. Y.

H. F. Reinhard is Chairman, AWS Committee on Safety Recommendations; Manager, Safety Codes Department, Union Carbide and Carbon Corp.

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Note: To assure that your copy of the Welding Journal is mailed to your new address, this change of address notice must be received at American Welding Society, 33 West 39th Street, New York 18, N. Y., no later than the 25th of the month previous to issue mailing.

Section News and Events

as reported to Catherine O'Leary

New Section Officers for 1955–56 Fiscal Year

The names of some of the new AWS Section Officers for the 1955–56 fiscal year have been given in previous issues of THE WELDING JOURNAL, particularly in the September issue. Listed below are the additional officers whose names have been received at AWS headquarters during the last month. If needed, the individual addresses may be obtained by writing to the Section Secretaries.

Arizona—Chairman, William F. Fischer; 1st Vice-Chairman, Larry L. Klemmer; 2nd Vice-Chairman, Bill Garland; Treasurer, Robert W. Sferra; Chr. Membership Committee, Earl W. Newhouse; Chr. Program Committee, Larry L. Klemmer; Technical Representative, William A. Mills; Secretary, Keith Rousseau, P.O. Box 790, Phoenix, Ariz.

Chattanooga—Chairman, Pembroke O. Leach; 1st Vice-Chairman, John A. Hardy; Treasurer, Raymond E. Barrett; Chr. Program Committee, Roy Lorentz; Technical Representative, Roy Lorentz; Secretary, Peter S. Naar, American Bureau of Shipping, 614 James Building, Chattanooga, Tenn.

Columbus—Chairman, Joseph E. Brockmeyer; 1st Vice-Chairman, Roy B. McCauley; Chr. Membership Committee, Richard R. Grant; Chr. Program Committee, Roy B. McCauley; Technical Representative, William L. Green; Secretary, Robert A. Bowers, 2911 E. Moreland Ave., Columbus 9, Ohio

Indiana—Chairman, Gilbert L. Foster; 1st Vice-Chairman, Michael G. Schaefer; 2nd Vice-Chairman, Edman F. Holt; Treasurer, Fred Watts; Chr. Membership Committee, E. F. Holt; Chr. Program Committee, Michael G. Schaefer; Technical Representative, C. A. Heffernon; Secretary, Mercedes Spotts, P. R. Mallory & Co., Inc., Indianapolis, Ind.

Long Beach—Chairman, Frank Pope; 1st Vice-Chairman, J. J. Carl; 2nd Vice-Chairman, Raul Treosti; Treasurer, John McClure; Chr. Membership Committee, Raul Treosti; Chr. Program Committee, J. J. Carl; Secretary, Carl Strong, 628 W. 220th St., Torrance, Calif.

Los Angeles—Chairman, F. V. McGinley; 1st Vice-Chairman, C. B. Smith; Chr. Membership Committee, J. B. Ross; Technical Representative, F. R. Drahos; Secretary-Treasurer, D. P. O'Conner, 3222 Sheffield Ave.,

SECTION MEETING CALENDAR

OCTOBER 11th

HARTFORD Section. Villa Maria, Glastonbury, Conn. "Castings versus Weldments," by Sidney Law, Chapman Valve Co.

OCTOBER 14th

DETROIT Section. Engineering Society of Detroit. Dinner speaker, Foster Winter, J. L. Hudson Co. Technical meeting—"Resistance Welding in the Aircraft Industries." Speakers: P. G. Parks, Solar Aircraft Co., "Engine Manufacturing Side of the Aircraft Engine Industries;" Glenn Woodmancy, Boeing Airplane Co., "Oscillograph Instruments in Spot Welding Quality Control and Maintenance."

OCTOBER 21st

ALBUQUERQUE, N. MEX., Section. 8:00 P.M., Industrial Arts Building, University of New Mexico. Discussion and Demonstration of Stud Welding Process by representative of Stud Welding Co.

MARYLAND Section. "Selection of Electrodes," by Perry Arnold, Chicago Bridge and Iron Works.

YORK-CENTRAL PA. Section. Bus trip to Philadelphia to attend National Metal Congress and Exposition. Bus leaves square in York with a pick-up at Lancaster, Pa., at 9 A.M.

MAHONING VALLEY Section. "Manufacture of Heavy Wall Pipe," by N. C. Jessen, asst. supt., Babcock & Wilcox Co., Boiler Div., Barberton Works.

OCTOBER 24th

CORPUS CHRISTI, TEX., Section. "Fabrication of Bridge Plate Girders by Submerged Arc Welding," by Joe H. Hoffman, asst. shop supt., Bethlehem Steel Co., Beaumont, Tex.

OCTOBER 25th

SAN ANTONIO, TEX., Section. (See October 24th for subject and speaker.)

SANTA CLARA VALLEY Section. "Metallurgy and Pressure Vessels," by Howard N. Sims, Black, Sivals and Bryson, Inc., Oklahoma City, Okla.

OCTOBER 26th

HOUSTON, TEX., Section. Ben Milam Hotel, 6:00 P.M. (See October 24th for subject and speaker.)

OCTOBER 27th

BEAUMONT, TEX., Division. (See October 24th for subject and speaker.)

MADISON, WIS., Section. "Welding and Cutting of Cast Iron."

NIAGARA FRONTIER Section. Hotel Sheraton, Buffalo, N. Y. 6:30 P.M. "Silver Brazing" by A. N. Setapen, Handy & Harman.

OCTOBER 28th

AUSTIN, TEX., Division. (See October 24th for subject and speaker.)

NOVEMBER 7th

LEHIGH VALLEY Section. R. D. Stout, Professor of Metallurgy, Lehigh University, Bethlehem, Pa., "Fundamentals of Welding."

NOVEMBER 9th

CLEVELAND Section. Hotel Manger, East 13th & Chester Ave. Dinner at 6:30 P.M. "Fixture and Material Handling for Various Welding Processes," by Cecil C. Peck, president of Cecil C. Peck Co.

NOVEMBER 17th

HARTFORD Section. Griswold Inn, Essex, Conn. Clarence Jackson, Metals Research Laboratory, Niagara Falls, N. Y. District Director, District No. 3.

MADISON, WIS., Section. Beloit Meeting. "Tool and Die Welding," by L. D. Richardson.

NOVEMBER 18th

MARYLAND Section. Engineers Club, 6 W. Fayett St., Baltimore, Md., 8 P.M. "Inert Gas Arc Welding and Carbon Dioxide Shielded Arc Welding," by G. R. Rothschild, Air Reduction Co., Inc., Murray Hill, N. J.

Editor's Note: Notices to be published in any one given issue must reach Journal office not later than the first of the preceding month. Give full information concerning time, place, topic and speaker for meeting.

ACCO products

3 Big Reasons for Buying PAGE Automatic Welding Wire

1. Packaged to fit your particular requirements

2. A wide range of analyses to fit a particular job

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Page Offers 26 Analyses in Automatic Welding Wire

In order to provide you with *exactly* the correct automatic welding wire for your specific requirements—no matter how "special" or "different" they may be—PAGE offers no less than 26 different analyses from which to choose. These "cover the waterfront" of applications: heavy automatic submerged arc...light manual submerged arc ...inert gas manual and automatic, tungsten or metal arc.

Carbon Steel • Any carbon from Armco (.025 max.) to high carbon (.90—1.10). All standard AISI analyses in between.

Low Alloys • All the most popular welding grades

Stainless • AISI grade. Other types on request

Following is a list of the *26 analyses* in which PAGE Automatic Welding Wire is readily available:

Page A-S-Armco	Page A-S-110
Page A-S-6	Page A-S-15
Page A-S-10	Page A-S-15-MO
Page A-S-17	Page A-S-3½-Nickel
Page A-S-20	Page A-S-6150
Page A-S-65	Page A-S-4130
Page NAX-9115	
Page-Allegheny A-S-Type 304	
Page-Allegheny A-S-Type 308	
Page-Allegheny A-S-Type 308 ELC	
Page-Allegheny A-S-Type 309	
Page-Allegheny A-S-Type 310	
Page-Allegheny A-S-Type 316	
Page-Allegheny A-S-Type 316 ELC	
Page-Allegheny A-S-Type 347	
Page-Allegheny A-S-Type 348	
Page-Allegheny A-S-Type 410	
Page-Allegheny A-S-Type 420	
Page-Allegheny A-S-Type 430	
Page-Allegheny A-S-Type 502	

Details of all these analyses are contained in our new Folder DH-402. Write for it!

from Page's Wide Range You Can Get Exactly the Analysis You Need for Each Welding Job

• The *right* electrodes and the *right* rods for every welding job! That is what you must have for perfect operation—and that is what you can expect from the wide range offered by PAGE. Choose what you need from this complete line:

Gas Welding Rods

Armco Gas (GB-45)	Page Armco
Mild Steel (GA-50)	C Gas
Low Alloy (GA & GB-60)	Hi-Tensile M
3½% Nickel (GB-65)	3½% Nickel

Bare Electrodes

Armco	Page Armco
Low Carbon	Page "CE"
.13—.18 Carbon	Page "B"
.55—.65 Carbon	Medium Carbon
.90—1.10 Carbon	High Carbon
Manganese Bronze	Manganese Bronze
Naval Bronze	Naval Bronze
Stainless Steel	According to AWS analysis

Any Page A-S Automatic Grade in 36" Lengths

Metal Spray Wire

Armco	Page Armco
.10 Carbon	#10
.28 Carbon	#25
.40 Carbon	#40
.60 Carbon	#60
.80 Carbon	#80
1.00 Carbon	#100
3½% Nickel	3½% Nickel
Manganese Bronze	Manganese Bronze
Naval Bronze	Naval Bronze
Stainless Steel Metal Spray	According to AWS Analysis

Convenient Service from Local Stocks

• Whenever you are in need of automatic welding wire, electrodes or welding rods, you can get them quickly and easily from your nearby PAGE Distributor—no matter what part of the country you live in.

PAGE Distributors carry ample stocks from which your requirements can be filled without delay or inconvenience to you. This handy service not only saves you time in getting what you need, but makes it unnecessary for you to make a sizeable investment in inventory. Thus, your nearby PAGE Distributor is able to make double savings for you—a saving in time and a saving in actual dollars.

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Milwaukee—Chairman, Joseph H. Stevens; 1st Vice-Chairman, Francis J. Harencki; Chr. Membership committee, Louis L. Ahsinger; Technical Representative, Robert J. Keller; Secretary-Treasurer, Anton L. Schaeffler, 623 N. 99th St., Wauwatosa 13, Wis.

Northern New York—Chairman, R. M. Rood; 1st Vice-Chairman, R. A. Gilbert; 2nd Vice-Chairman, W. F. Savage; Chr. Program Committee, R. A. Gilbert; Technical Representative, W. F. Savage; Secretary-Treasurer, J. P. Frandsen, 457 6th Ave., North Troy, N. Y.

Like a magic carpet for overhead welding

Send for FREE CATALOG

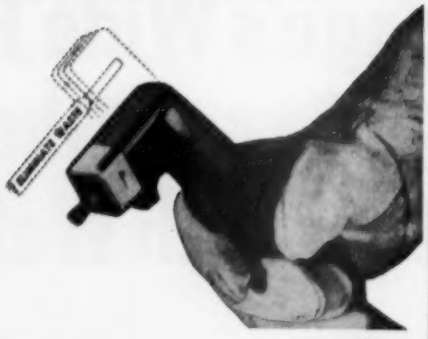
*TWECO-LITE, the new flexible ALUMINUM welding cable that weighs half as much, costs less and lasts longer.

a product of TWECO PRODUCTS CO. Wichita 1, Kansas

BERNARD

PIONEER FOR MODERN WELDING

"Shortstub" ELECTRODE HOLDER



The jaws substitute for stub waste by splicing a 2 inch extension to the length of every electrode.

"Multi-Pic" CONTOUR CLEANER

Delivers FIVE surface cleaning blows with each swing and lasts FIVE times longer than single headed hammers.

"Pro-Clamp" MECHANICAL HANDS

MODERNIZE the fabrication of plates, shapes, rods, bars, pipes, etc. MAKE fitting, positioning, holding, and welding a fast, accurate, inexpensive, one-man job.

See your Local Dealer, or, Write For Bulletins, SS-3, MP-6 and PCB-6

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Salt Lake City—Chairman, Darwin Christofferson; 1st Vice-Chairman, Paul Ownby; 2nd Vice-Chairman, Ray Potts; Treasurer, Ed. S. Brown; Chr. Membership committee, Paul Ownby; Chr. Program Committee, Ray Potts; Technical Representative, L. A. Pope; Secretary, Joe Roberts, 1862 Sycamore Lane, Murray 7, Utah

San Francisco—Chairman, Charles B. Robinson; 1st Vice-Chairman, Robert C. McCormick; Treasurer, Bernard P. Faas; Chr. Program Committee, Fred Stetner; Technical Representative, S. I. Roberts; Secretary, Lawrence Robbins, Mare Island Naval Shipyard, Ship Superintendent, Code 354, Vallejo, Calif.

Worcester—Chairman, William J. Ryngiewicz; 1st Vice-Chairman, Robert E. Smith; 2nd Vice-Chairman, Frank A Smelowiez; Treasurer, Edwin W. Spellman; Chr. Membership Committee, John L. Perry; Chr. Program Committee, Robert E. Smith; Technical Representative, John C. Kasabula; Secretary, Clifford H. Murray, 344 Brooks St., Worcester, Mass.

Section Secretaries:

Section Meeting Calendar notices to be published in any one given issue must reach the JOURNAL office not later than the first of the preceding month. Please give full information concerning time, place, topic and speaker for meeting.

for Better Welding Production...

INDUSTRIAL *Plug-In* UNITS!

Welding Press Control illustrating simple removal of plug-in electronic timer

Plug-In TIMERS

are designed to stand up under hard industrial usage. Both timers and sequencing relays can be installed in a matter of seconds. Down time is reduced to absolute minimum during replacement. Timing circuits are fail-safe—if any tube fails to fire, circuit will be opened and welding process stopped instantly.

Plug-in relays being removed from welding press controller Faster electrical maintenance

Plug-In RELAYS

are of special rugged industrial design and construction. Flexibility provided by plug-in feature (on both sequencing relays and timers), permits easy circuit changes without complete controller redesign.

Write for Bulletin 8991

Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin

SQUARE D COMPANY

New Members

Effective August 1, 1955

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A—Sustaining Member B—Member C—Associate Member D—Student E—Honorary Member F—Life Member

ALBUQUERQUE
Glover, Eldon E. (C)

BOSTON
Caliri, Frank (C)

BRIDGEPORT
Cretella, Salvatore J. (B)

CHATTANOOGA
Blevins, O. N. (C)

CHICAGO
Lawton, Clifford C., Sr. (B)
Lee, Louis K. (C)

CLEVELAND
Forsthoefel, F. W., Jr. (B)
Hopkins, Harvey J. (C)
Thatcher, Maurice W. (B)

DALLAS
Cobb, William L. (C)
Rollins, H. M. (B)

DAYTON
Klank, W. C., Jr. (C)

DETROIT
Lofland, J. E. (C)
Maganus, Paul Guy (B)

HOLSTON VALLEY
Evans, T. D., Jr. (B)

HOUSTON
Dailey, Elliot E. (B)
Fagal, Robert W. (B)
Korn, C. V. (C)
Ligon, Larry N. (B)
Rouse, Robert J. (B)

KANSAS CITY
Hamm, John E. (B)

LONG BEACH
Hardesty, E. E. (B)

LOS ANGELES
Butz, Raymond A. (B)
Drees, Matthew (C)
Landusky, Claude A. (B)
McKern, Fred (C)
Sheehan, John J. (C)

NEW JERSEY
Doty, Benjamin F. (B)
Slinger, Walter H. (B)

NORTHEAST TENNESSEE
Felix, H. L. (B)
Henson, E. L., Jr. (B)

OKLAHOMA CITY
Champion, Ward M. (C)

PHILADELPHIA
Bell, Edwin E. (B)
Boyjian, Richard D. (B)
Carmichael, Richard L. (B)
Collins, John C. (B)
Cummings, Mathew (B)
Fitzgerald, David W. (B)
Headley, Laurence H. (B)
Krall, George (B)
Lindquist, John (B)
Sheehan, Edward F., Jr. (B)
Weismantel, E. E. (B)
Zimmer, William H. (B)

PITTSBURGH
Lee, Robert E. (B)

PUGET SOUND
Finnegan, W. D. (B)

SAGINAW VALLEY
Reynolds, Floyd E. (D)

ST. LOUIS
Fayer, Raymond R. (C)
Fox, Charles B., Jr. (C)
Mathews, Joseph P. (C)

SAN FRANCISCO
Albert, Doug (B)
Enright, Carleton J. (C)
Tinnes, Leroy (C)

SUSQUEHANNA VALLEY
Belford, Albert F. (B)
Hamelin, Bernard P. (B)
Keating, Arthur E. (B)

TRI-CITIES
Barnes, Hugh (C)
Edwards, Herman L. (C)

WICHITA
Brown, C. S. (B)

YORK-CENTRAL PA.
Hoke, Donald E. (C)

NOT IN SECTIONS
Labate, Vincent J. (B)
Lone, John (D)
Winterton, Kenneth (B)

Members Reclassified During the month of August

CLEVELAND
Ashmus, William (C to B)

COLUMBUS
Green, William Lee (D to C)

MAHONING VALLEY
Liptak, James A. (C to B)

NORTHWESTERN PA.
Maider, Harold A. (C to B)

ROCHESTER
Rotherwel, Roy R. (C to B)

SAGINAW VALLEY
Housen, Carrol (C to B)

AWS Needs Your Help . . .

For many reasons, too many to enumerate here, it is essential that membership of AWS be expanded.

Not only the future of welding, its greater acceptance and expansion, but also your own future, depends on the continued growth of AWS.

Your membership in AWS is a responsibility as well as an advantage. You get from the Society what you put into it—except that your contribution grows and pays dividends. As your industry expands so too do your own opportunities.

We want to double our membership this year. If you will personally be responsible for just *one new member* we can easily reach that goal. Will you?

Lew Gilbert, *Chairman*
National Membership Committee

September Journal Delayed by Floods

The August 18th and 19th floods that devastated some sections of Pennsylvania fortunately brought no great physical damage to the facilities of the Mack Printing Co. in Easton, but plant operations were disrupted sufficiently to delay the production of the September Journal by several days. This accounts for our lateness in the mailing of that issue.

We are very grateful to the Mack Printing Co. for their tireless efforts in getting the September Journal out with the minimum amount of delay, and we thank our fellow members, our subscribers and our advertisers for their patient understanding and cooperation.

The Editors

ABSTRACTS OF CURRENT PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,713,716—Method of Repairing Cracks in Cylinder Blocks—Horace K. Treadwell, Jonesboro, Ga.

This method is for repairing cracks in cylinder blocks wherein the cracks extend from a valve port into a cylinder bore. The method includes drilling through the crack from the base of the valve seat into the cylinder bore and plugging such bore after it has been threaded. Then a hole is drilled across the crack at the upper surface of the cylinder block, the walls of the crack are pulled toward each other and then the crack is welded.

2,714,150—Resistance Spot Welder—Walter S. Kaiser, Highland Park, Mich.

This patented resistance welder is adapted to be operated and cooled by fluid means. The welder includes a welding gun having a pressure cylinder, and a piston suitably mounted in the cylinder and having a piston rod extending outwardly of the pressure cylinder. Lost-motion means connect a welding electrode to the piston rod and means are provided for moving the piston in both directions in the cylinder. A cooling system is connected to the cylinder and is adapted to increase the fluid pressure during the return stroke. Other means are provided for connecting the cooling system to the welding electrode for cooling action thereon.

2,714,198—Ground Connector for Electric Welding—Harry F. Schloetzer, Topeka, Kan.

In this patent, a special ground connector is provided and includes a stationary jaw member having a forward end terminating at an anvil portion. A movable jaw is carried on the stationary jaw member by specialized link and lever means so that the relative spacing between the movable jaw and the stationary jaw is determined by the pivotal mounting of the movable jaw and a control lever on the stationary jaw.

2,714,760—Method of Brazing and Joint Produced Thereby—Willard M. Boam, Fair Lawn, and Herman H. Hanink, Ridgewood, N. J., assignors to Curtiss-Wright Corp., a corporation of Delaware.

A method of brazing a pair of corrosion and oxidation-resistant high-temperature alloy parts together is disclosed in the patent. In the method, the surfaces of the parts to be brazed together are positioned in abutting relation and then a mixture containing a brazing alloy in powdered form is placed on the parts along one or more edges of the abutting surfaces. The mixture includes a binder for the brazing alloy which consists essentially of 8–20% chromium, 2–5% boron and 65–85% of a metal from the group consisting of nickel and cobalt. The parts are heated to a temperature of at least 2000° F for melting the brazing alloy to braze the parts together. The parts are maintained in a dry reducing atmosphere of hydrogen during the brazing operation.

2,715,172—Deep-Hole Electrode—John S. Larkins, Jr., Detroit, Mich., assignor to Elox Corp. of Michigan, Clawson, Mich., a corporation of Michigan

Larkins' patent relates to a new type of an electrode for cutting deep holes in metal work pieces by electrical discharge. The electrode includes an elongated body member of conductive material which has a passageway therein for providing flow of coolant into the hole. A guide member of dielectric material is secured to the body member and adapted to engage the wall of the hole to provide clearance between the body and the wall for flow of coolant out of the hole and to center the body in the hole during the cutting action.

2,715,263—Method and Apparatus for Welding Metal—James MacGregor, Pittsburgh, Pa., assignor to York Engineering & Construction Co., Pittsburgh, Pa., a corporation of Pennsylvania.

This patented welding method includes the steps of surrounding the metal to be welded with a nonoxidizing medium and heating the metal up to welding temperature after nonoxidized surfaces have been prepared on the metal. The nonoxidized surfaces are pressed together and are thereafter removed from the nonoxidizing medium.

2,715,698—Power Control Circuit Particularly for Electric Resistance Welders—Joseph J. Riley and William S. Dustman, Warren, Ohio, assignors to the Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

This apparatus relates to the control of flow of electric power from an a-c source where a pair of discharge valves are connected in the inverse parallel relation and each has an ignition electrode and an associated grid-controlled discharge device for conducting current to the electrode. The improvement covered in the patent relates to the provision of a second pair of grid-controlled discharge devices energized from the source and applying biasing potentials to the grids of the first-mentioned discharge devices. Other means apply to the grids of the second pair of discharge devices periodic control potentials bearing preselected phase relation to the alternations of the source. A grid-controlled discharge device is connected in series in the energizing circuit for the second pair of discharge devices while a further grid-controlled discharge device is connected in parallel with the second pair of devices and the last named device. Other specialized control means are provided including energy storage means for applying a positive potential to the grid of the last-named discharge device for a part of the half cycle of the source following the cessation of conduction of the further discharge device referred to above.

BOUND VOLUMES OF 1954 JOURNAL STILL AVAILABLE

Bound Volumes of The Welding Journal for the year 1954 are available in black imitation leather covers, together with a comprehensive subject and authors index. Price $15, including postage.

This volume, comprising a total of 1238 pages in the Journal and an additional 624 pages in the *Welding Research Supplement*, represents a veritable encyclopedia of information in the welding field. Copies may be ordered through the American Welding Society, 33 W. 39th St., New York 18, N. Y.

NO SINGLE

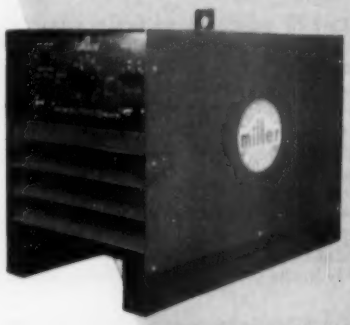
THERE'S EXACTLY THE RIGHT miller WELDER TO MEET EVERY WELDING REQUIREMENT

MILLER SR RECTIFIER TYPE DC ARC WELDERS

Available in 200, 300, 400 and 600 amperes, it is a superior direct current welder using Miller Unitran transformer control and selenium rectifiers for conversion from 3 phase AC line current. Miller SR Welders feature widest possible current range, extreme arc flexibility, maximum electrode deposition rate and highest electrical efficiency.

THE *New* MILLER SRH RECTIFIER TYPE DC ARC WELDER

A new concept in welder design for all DC metalic arc welding. Available in 200, 300 and 400 amperes. It is ruggedly constructed, compact, and is designed to lend itself to stacking for parallel operation or to conserve floor space. It has single range control and is weatherproof.



MILLER ARC WELDERS FOR TUNGSTEN ARC WELDING PROCESS

These Miller Welders feature the patented Miller UNITRAN control circuit which combines the transformer with its own integral flux diverter. This, in conjunction with adequate open circuit voltage, high frequency, balancing resistor and optional controls insures superior uniformity and flexibility throughout the entire welding range. Available in nine models.

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THE *New* MILLER MULTI ARC COMBINATION AC-DC WELDER

Available in 14 models, this new Miller Welder provides both AC and DC welding power for applications where both are required. It operates from a single phase power line and is available with high frequency and controls designed especially for inert gas arc and spot welding.

MILLER 100 SERIES HEAVY DUTY INDUSTRIAL TYPE AC WELDERS

Designed for heavy production welding and automatic welding applications. Available in eight models. The 100 Series Welders permit faster welding — as much as 35% faster. Movable coil design and 80 volts O.C.V. produces uniform and better welding characteristics throughout the entire range of the welder.

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NEWS of The Industry

I. W. D. A. Elects

The annual meeting of the Independent Welding Distributors Assn. was recently held at Carmel by the Sea, California. W. V. ("Doc") Raymond, president and general manager of California Welding Supply Co., Stockton, Calif., was elected president for the forthcoming year. Otto Koll, proprietor of the Welders Supply Service, Modesto, Calif, was elected vice-president and M. J. Andrews, secretary-treasurer.

The I. W. D. A. is an association of 25 independent welding supply distributors in the Western United States, Alaska and Hawaii. The organization was formed in 1948 in order that independent welding supply distributors might exchange information regarding business methods and trade practices. The next annual meeting of the Association will be held in San Diego, Calif.

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings
1955 Fall Meeting:
October 17–21, Bellevue-Stratford Hotel, Philadelphia, Pa.
1956 Spring Meeting:
May 8–12, Statler Hotel, Buffalo, N. Y.

NWSA Meetings
Luncheon Meeting
October 18, Bellevue-Stratford Hotel, Philadelphia, Pa.
West Central Zone:
October 31 and November 1, Hotel Phillips, Kansas City, Mo.
Western Zone:
November 3 and 4, Ambassador Hotel, Los Angeles, Calif.

RWMA Meeting
Luncheon Meeting:
12:30, October 18, Bellevue-Stratford Hotel, Philadelphia, Pa.

Attend

National Fall Meeting

October 17–21
Bellevue-Stratford Hotel
Philadelphia, Pa.

I. A. A. News

• The International Acetylene Assn., 30 East 42nd St., New York 17, N. Y., announces that the popularity of the I. A. A. film, "The Oxy-Acetylene Flame—Master of Metals," continues undiminished. At present rates the number of persons who have seen it (exclusive of TV showings) through Bureau of Mines Loan Service will pass the million mark in the first few days of 1956.

• The Bureau of Explosives "Report of the Director and Chief Inspector of the Bureau for the Safe Transportation of Explosives and Other Dangerous Articles" reveals that no reported accidents involving acetylene or oxygen occurred during 1954 in the transportation by rail freight and rail express.

• The Commission Permanente Internationale (CPI), an international society with headquarters in Paris, France, was organized many years ago to promote the best interests of the calcium carbide and acetylene industries. Its membership includes delegates from many countries. During 1956 it is sponsoring an international competition with a view to promoting the applications of the oxy-acetylene flame. Valuable prizes totaling 500,000 French francs (about $1430) will be awarded for the best papers. Participation in the competition is open to all except members of the staff of CPI. Also, a participant can enter more than one paper.

• Rather extensive revisions have been made to the I. A. A. "Safe Practices" pamphlet. This revised booklet is now printed and available for immediate distribution. One free copy will be sent to each I. A. A. member upon request. Additional copies can be had for twenty-five cents each, with discounts of 10% on orders for 50 to 100 pamphlets, and 20% on orders for 100 or more pamphlets.

• The Metropolitan Life Insurance Co. has just issued a revision of its pamphlet, "Health Protection in Welding." First written in 1937 it has been revised from time to time to keep it up to date with the art of welding. The present edition covers all forms of welding and is written specifically for persons who employ or supervise welders. It is intended to help them create safe working conditions for welders, to help them avoid hazards that may not be obvious and to guide them in first aid when accidents occur. A copy will be sent, free of charge, upon request to the Metropolitan Life Insurance Co., Safety and Occupational Health Bureau, 1 Madison Ave., New York, N. Y., or to the company's office in San Francisco or Ottawa.

Additional information on the above items may be had by writing to the association at the above address.

Union Carbide Forms Nuclear Company

Union Carbide Nuclear Co., a Division of Union Carbide and Carbon Corp., has been formed to integrate the corporation's diverse activities in the atomic energy field, it was announced today by Morse G. Dial, Union Carbide's president. Mr. Dial stated that an important objective of the new company will be to carry on large-scale research and development activities leading to increasingly important participation by the corporation in the industrial applications of atomic energy.

Kenneth Rush, a vice-president of Union Carbide, has been appointed president of the new company, and Lyman A. Bliss, Clark E. Center and Oscar F. Holmgren have been named vice-presidents. All of the new officers have played important roles in the corporation's atomic energy activities for many years.

Mr. Rush joined Union Carbide's Law Department in 1937 and was elected a vice-president of the corporation in 1949. He is presently in charge of all corporation activities outside of the United States and Canada and is a member of the Appropriations Committee. Mr. Rush will continue to carry on these responsibilities.

Mr. Bliss has been vice-president of Linde Air Products Co., the Division of Union Carbide and Carbon Corp. concerned with industrial gases, welding processes and silicones. Mr. Bliss was intimately associated with the corpora-

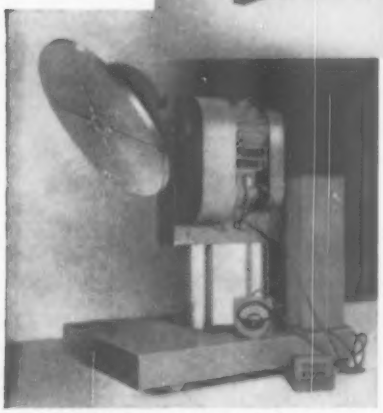
Steady, Positive, Precision Rotation for AUTOMATIC WELDING with *Aronson* Positioning Equipment.

These are only a few examples of the Quality and utility of Aronson Positioning Equipment (Write for New Catalog and prices)

TracTred (T. M. Reg.) Turning Rolls for thin-walled heavy cylindrical work to 18 tons capacity. Zero to 100 IPM turning speed and Built-In Grounding.

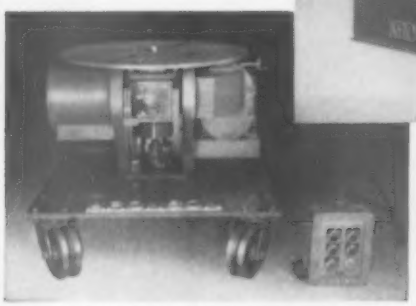
Heavy Duty Precision Built Rubber and Steel Tired Turning Rolls, 100% overload protected. Capacities to 150 Tons. Also Tilting Rolls, Pipe Rolls and Rail Cars.

Heavy Duty Gear Driven Positioners, with Magnetic Braking, Mercury Grounding, and Optional Speeds. Capacities to 24,000 lbs.

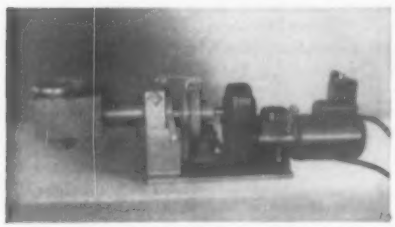


Fully Automatic Gear Driven Positioners, featuring Power Elevation, Tilting and Rotation. Capacities to 21,000 lbs.

Heavy Duty Floor Turntables with precision speed control and Magnetic Braking, used for welding, burning, X-raying, etc. Capacities to 75,000 lbs., various heights and speeds.

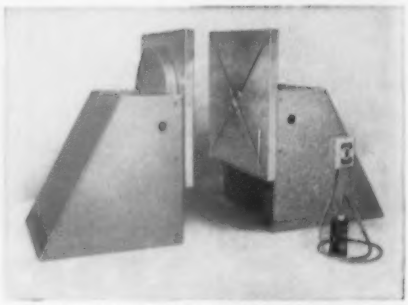


Model D Gear Driven Positioners, Compact, Precise, Rugged. Capacities to 1000 lbs.



Bench Turntable Automatic Positioners. Capacities to 500 lbs.

Aronson Universal Balance Positioners position your weldments effectively, instantly for downhand welding. Capacities to 2000 lbs.



Rugged Head and Tail Stock for positioning bulky weldments between centers. Table Backup for Zero Deflection, Magnetic Braking. Capacities to 160,000 lbs.

Aronson-Twinner Permanent Magnetic Clamps, six models with thousands of uses in welding set-up work. Write for bulletin.

Aronson MACHINE CO. ARCADE, N. Y.

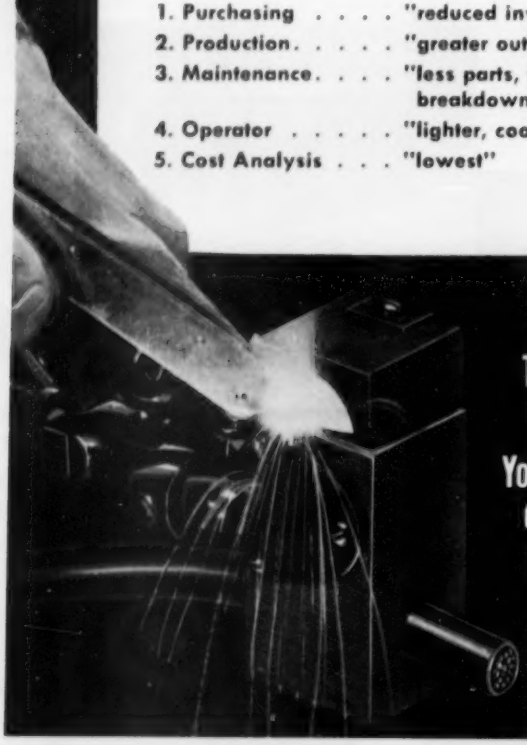
HAS YOUR PLANT TRIED

CADDY?

CADDY Arc Welding Accessories are all designed to utilize the finest of all electrical connections—CADWELD. From welding machine to electrode, the CADWELD connection has revolutionized the arc welding circuit. Today after five years of on the job analysis, companies all over the United States are standardizing on CADDY Arc Welding Accessories and CADWELD cable splicing.

The reason for the acceptance of the complete CADDY Arc Welding Circuit is that it proves itself to:

1. Purchasing . . . . "reduced inventory"
2. Production. . . . . "greater output"
3. Maintenance. . . . "less parts, fewer breakdowns"
4. Operator . . . . . "lighter, cooler"
5. Cost Analysis . . . "lowest"



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tion's participation in the development of the gaseous diffusion process and other activities of the Manhattan Project, which were subsequently taken over by the Atomic Energy Commission. As vice-president of the new company he will direct the research and industrial activities.

Mr. Center has been vice-president of Carbide and Carbon Chemicals Co., a Division of Union Carbide and Carbon Corp. Mr. Center will continue to be responsible for the direction of the corporation's operation of the Atomic Energy Commission's plants at Oak Ridge and Paducah, and of Oak Ridge National Laboratory.

Mr. Holmgren has been executive vice-president of United States Vanadium Co., a Division of Union Carbide and Carbon Corp., which is a principal producer and processor of uranium ores. As vice-president of the new company, he will be responsible for administrative activities and will also continue to participate, on a policy level, in matters pertaining to the mining and milling of ores.

Diversey Names New Division Manager

The appointment of J. O. Slaybaugh as division manager of The Diversey Corp.'s Cleveland Division was recently announced by W. E. Noyes, vice-president in charge of sales.

Slaybaugh joined Diversey's sales staff in 1941. After serving in the armed forces during World War II, he returned to the company as a field representative. Successive promotions to district manager in 1951 and assistant division manager in 1954 led to this new assignment.

The Diversey Corp. manufactures specialized cleaning and sanitizing compounds for the metals industry.

New K-G Distributors

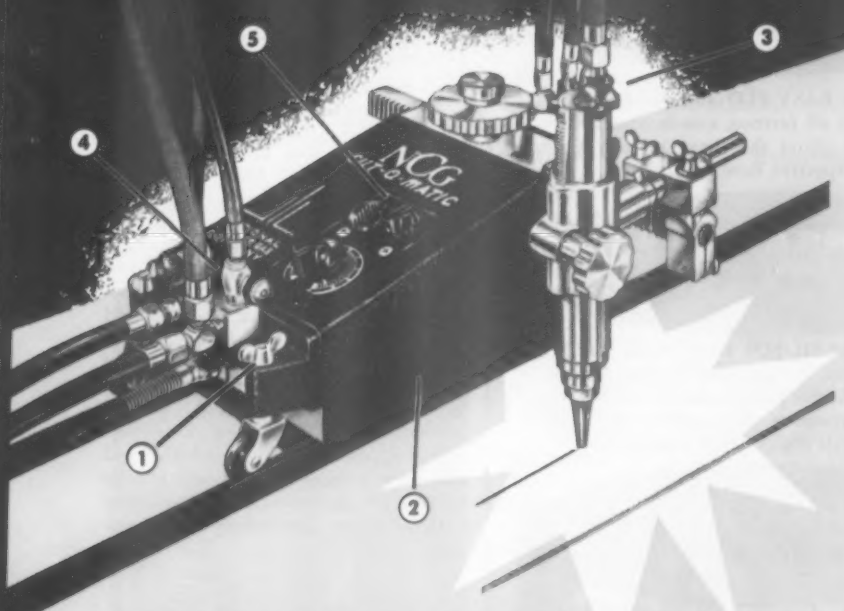
Appointment of the following new distributors has just been announced by the K-G Equipment Co. Inc., Allentown, Pa., manufacturers of welding and cutting equipment for industry and oxygen therapy equipment for the medical profession:

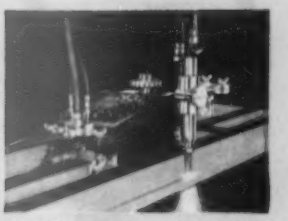
Austin Oxygen Co., 503 Neches St., Austin, Tex.; Central Welding Sales Co., 347 Cannon St., E., Hamilton, Ontario, Canada; Claudin Welding Supply Co., 13 East Washington St., Champaign, Ill.; Fayette Oxygen & Supply Co., Box 1508, Uniontown, Pa.; Harris Welding & Service Co., 6915 Crescent Blvd., Camden, N. J.; Medico Electric Motor Co., 11 Tompkins St., Pittston, Pa.; Tri-State Welding Supply Co., 1122 Johnson St., Keokuk,

More Accurate, Lighter Weight

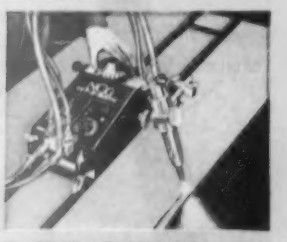
NEW CUT-O-MATIC® NO. 7

PORTABLE FLAME-CUTTING MACHINE

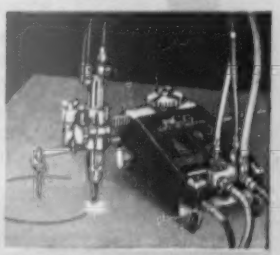




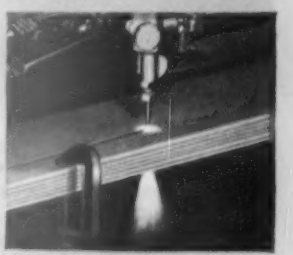
Straight Line Cutting—A 5-foot section of rigid track is supplied with each machine. By using two lengths progressively, a straight cut of unlimited length can be made in one continuous operation.



Bevel Cutting—Straight or circle cuts can be made to any bevel angle by a simple adjustment of the **Cut-O-Matic** torch holder



Circle Cutting—True circles and arcs, 3 inches to 60 inches in diameter with either square or bevel edges, are cut easily by attaching the radius rod assembly furnished with each machine.



Stock Cutting—Where many pieces of the same dimensions are needed, stock-cutting with the **Cut-O-Matic No. 7** provides real production line economies. Simply clamp plates as shown and use larger size cutting tip.

1 New torch stabilizing device brings new cutting accuracy—A new, unique *floating rear caster* assembly practically eliminates machine wobble and side tilt, when passing over rough, unevenly surfaced plate. Gives production-line accuracy, clean, smooth edges, no finishing.

2 New design cuts 20 lbs. off weight—Almost unbelievably, this new improved CUT-O-MATIC now weighs less than 30 lbs., for ready portability, greater ease of handling—yet it's more rugged than you'll ever need.

3 New 3-hose torch now spells improved cutting efficiency—The new CUT-O-MATIC 3-hose torch has individual oxygen hose to both preheat and cutting orifice, simplifying preheat oxygen adjustment and assuring more efficient cuts.

4 New simplified Gas control—A new valve block assembly now locates preheat controls on machine, separated from high pressure oxygen control on the torch. Adjustments on preheat now made freely without disturbance to oxygen control.

5 New switch is maintenance-free for life of machine—New rotary-type switch, exclusive with NCG, provides trouble-free starting, stopping and reversing for life of machine. Has silver electrical contacts, is permanently sealed against grit and dirt.

CUT-O-MATIC has been redesigned throughout, offers many more advantages than those mentioned here. No other portable flame-cutting machine like CUT-O-MATIC. Get proof, the full story. Ask for a demonstration or write for new big broadside from any authorized NCG dealer or nearest NCG office or address below.

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The amazing VERSATILITY of EASY-FLO and SIL-FOS

You'd have to go a long way to find a brazing job that these low-temperature silver brazing alloys can't do.

VERSATILITY IN METALS

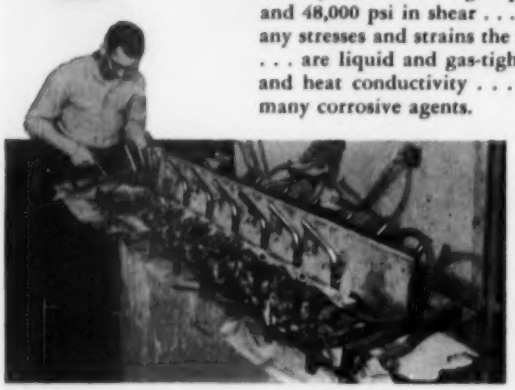
Between them, the EASY-FLO and SIL-FOS alloys will join practically all ferrous, non-ferrous and dissimilar metals and alloys that have melting points above the alloys' respective flow points.

VERSATILITY IN HEATING METHODS

The EASY-FLO and SIL-FOS alloys work well with all . . . oxyacetylene, natural and city gas torches – gas-air burners – oil, gas and electric furnaces – electric induction, resistance or incandescent carbon – molten alloy or salt dip . . . take your pick.

VERSATILITY IN JOINTS

EASY-FLO and SIL-FOS naturally and consistently make joints that . . . go up to 130,000 psi in tension and 48,000 psi in shear . . . have the ductility to take any stresses and strains the metals they join can stand . . . are liquid and gas-tight . . . have high electrical and heat conductivity . . . offer strong resistance to many corrosive agents.



In the job shown here induction heating is used to braze steel handle bars to stems with EASY-FLO 35 – 6 at a time in 32 secs. The two jobs shown at left above are gas torch brazed with EASY-FLO 45.

ADD to their 3-ply versatility the fact that their low flow points protect metals and save gobs of time, labor and heat – and you have every reason to standardize on the EASY-FLO and SIL-FOS alloys for all your brazing.

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There's no "...or equal" for EASY-FLO and SIL-FOS

Iowa; Welding Process Equipment Co., 1302 Bryn Mawr, Chicago, Ill.; Philip Wolf and Son, 424 East Walnut St., Lewistown, Pa.

New Square-D Plant

Square D Co. will begin construction immediately on a new plant to be located in Royal Oak, Mich., and has begun production at two recently completed units in Cedar Rapids, Iowa, and Secaucus, N. J., stockholders were told by F. W. Magin, president, in the company's semiannual report mailed August 10th. With the Royal Oak plant scheduled for "substantial completion" this year, the combined new facilities will represent one-quarter million square feet of manufacturing floor space added in 1955, Mr. Magin said.

Square D, which will have 12 plants at the end of the year—10 in the U. S. and others in Toronto and Mexico City—has more than doubled manufacturing facilities since the end of World War II. The Distribution Equipment Division, Detroit, manufactures safety switches, circuit breakers, switchboards, lighting and power panels, and related products. The Industrial Controller Division, Milwaukee, makes high-speed electronic welding devices and a wide variety of motor controls, the latter with extensive application in automation.

Gunzelman to Manufacture Welding Equipment

Willard (Curley) Gunzelman, closely associated with engineering and fabrication of automatic welding equipment for the past 12 years, has announced formation of a new manufacturing company.

Known as World Electric Co., with engineering and sales offices in Cleveland Heights, Ohio, the company will market a complete line of equipment carrying the "Welco" trademark. Engineering, servicing and consultation services for all types of welding operations have also been announced.

Included in the new Welco line of standard and special machines are mast and boom types from 5 ft lift and ram to 20 ft lift and ram, new type seam welders, head and tailstocks and constant centerline turning rolls. Experienced representatives have been appointed in most major marketing areas. Equipment for spot welding, high-production resistance welding, and metallic, submerged and inert automatic arc welding is in current production.

World Electric also represents Banner Welder, Inc., of Milwaukee for all

types of spot, projection and seam welders and the Harnischfeger Corp. for its line of engineered welding positioners.

Union Carbide to Build New Home Office Building in Grand Central Area

Morse G. Dial, president, Union Carbide and Carbon Corp., has announced that the corporation has arrived at an agreement to buy an option held by the New York Central Railroad which will enable Union Carbide to purchase the long-term leasehold on the entire block between Park and Madison Aves., and 47th and 48th Sts. Mr. Zeckendorf, president of Webb & Knapp, Inc., represented the New York Central.

Mr. Dial said that Union Carbide proposes to erect on this site a modern 41-story building for the new home offices of the corporation and its divisions and subsidiaries.

All features needed for the efficient conduct of the corporation's business, and for the convenience and comfort of employees, will be incorporated in the new building. Offices will be fully air-conditioned, and advantage will be taken of the site to provide a maximum of natural light. Employee service facilities will include a completely equipped medical unit, lounge areas and an employees' cafeteria.

While the terms of the leasehold agreement with the New York Central were not announced, it is anticipated that the building project will involve an investment of approximately 40 million dollars. It is expected that the new building will be ready for occupancy some time in 1958.

The new building will permit the consolidation in one location of the home offices of the corporation, and its divisions and subsidiaries, including among others: Bakelite Co., Carbide and Carbon Chemicals Co., Carbide and Carbon Realty Co., Electro Metallurgical Co., Linde Air Products Co., National Carbon Co., Pyrofax Gas Corp., Union Carbide International Co., Union Carbide Nuclear Co.

Announcement of the present plans confirms the decision of Union Carbide not to go further at this time with the proposals for building facilities on its land purchased in 1952 in Westchester County. The corporation contemplates holding this land near Elmsford in Westchester County for future expansions appropriate to that community.

Metal & Thermit Expanding Facilities

A combined general office, research and distribution center representing a total investment of over $2,000,000 will be established in Rahway, N. J., by Metal & Thermit Corp., H. E. Martin, president of the corporation, has announced. Located on a 17-acre tract on Rahway Ave., it is scheduled for completion in April 1956.

At that time, the company's executive offices will also be moved to new quarters at 100 Park Ave., New York City, to provide more space for future growth, Mr. Martin said. These offices will be occupied by the firm's senior officers, sales and production executives, technical and executive advisory staff and New York District sales personnel.

The new center at Rahway will include a general office building, a distribution warehouse and a central steam plant as well as the company's existing Research facility which is being expanded.

Erection of the new center, which will house the company's general offices

and will replace existing warehouses and sales offices in Newark and Philadelphia, was made necessary by expansion of the company's activities, according to Mr. Martin. Relocation of its facilities will enable the company to operate on a more efficient basis and to provide better service for its customers on the eastern coast.

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15 improve work on aluminum and aluminum alloys. The number for cast iron is 10. For copper and copper-bearing alloys - 12 . . . for nickel - 8 . . . . for stainless steel — 10 . . . for steel - 20 . . . . . for variety of metals - monel - magnesium - zinc die cast - 11

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Q. Why?

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BUFFALO, N. Y.
Brace-Mueller-Huntley, Inc.
Whitehead Metal Products Co., Inc.

CAMBRIDGE, MASS.
Whitehead Metal Products Co., Inc.

CHARLOTTE, N. C.
Edgcomb Steel Co.

CHICAGO, ILL.
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†Steel Sales Corporation
Corey Steel Co.

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Williams & Co., Inc.

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SYRACUSE, N. Y.
†Brace-Mueller-Huntley, Inc.
Whitehead Metal Products Co., Inc.

TAMPA, FLA.
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TOLEDO, OHIO
Williams & Co., Inc.

TULSA, OKLA.
Metal Goods Corp.

YORK, PA.
Edgcomb Steel Co.

†Home Office

"Seawolf" Launched at Groton

The Navy's accelerated program of nuclear submarine construction was visibly demonstrated on July 21 with the launching of the atomic "Seawolf" and the keel laying for a third unnamed nuclear sub.

Both events took place at the shipyard of the Electric Boat Division of General Dynamics Corp. but there was little similarity between the two. Only a handful of officials and yard workmen were on hand for the early morning keel laying.

In contrast, the colorful "Seawolf" launching, four hours later, was witnessed by an estimated 25,000 spectators, including high officials of the Navy and Defense Departments and the U. S. Atomic Energy Commission, Congressional leaders, and representatives of Canada, Colombia, France, Italy, Peru and Japan.

Sponsor of the "Seawolf," third Navy submarine to bear the name, was Mrs. W. Sterling Cole, wife of Rep. Cole of New York.

The crowd heard Secretary of the Navy Charles S. Thomas declare "the production of nuclear-powered vessels by the Navy has come of age." Citing Congress' approval of the Navy's plans to build four more nuclear submarines, Thomas added "this means that this fiscal year the Navy will have eight nuclear-powered submarines in being or under construction, and in rapid succession thereafter, many others."

Looking ahead, Thomas said "our future plans include nuclear powered vessels of other types. Development of nuclear propulsion for larger Navy ships is well advanced."

Chairman Lewis L. Strauss of the AEC called the "Seawolf" launching another important achievement in the development of atomic power. "It signifies. . . the leadership and determination of American democracy and free enterprise to advance the day when atomic power will greatly enrich our lives and the lives of peoples everywhere," Strauss said.

Swiss Acetylene Society Reports for 1954

In Swiss economic history, the year 1954 will rank among the best. In the machine industry there were more orders than in 1953. Prices tended to rise in the second half of the year. Exports in the electrical industry reached a peak since the war. The metal working industry remained at about the same level as in 1953. There was a small increase in consumption of carbide and welding gases. Interest in automatic arc welding continued to increase.

The Swiss Acetylene Society gave 26 theoretical and practical courses on welding to 478 participants in 1954. The Society's magazine published 12 issues, 262 pages, and there was an increase in advertising and foreign subscriptions. The technical committee advised members on a wide variety of topics, including gas welding fluxes, gases for bright annealing stainless steel, acid-free soldering fluxes for steel, repair of corroded aluminum gasometers, welding polyvinyl chloride plastics, and fluxes for silver soldering diamonds.

The Society produced a moving picture on weld testing. The Society's library now has 1607 volumes and 85 films. At the end of 1954 the membership amounted to 1308. Dr. P. Schlapfer was elected president for the 1955–56 season.

PERSONNEL

Chandler Promoted

Barron W. Chandler has been appointed District Sales Manager for P. R. Mallory & Co., Inc., in the company's Indianapolis district. Chandler was formerly a sales representative in the Mallory sales office in Philadelphia.

Chandler attended the U. S. Naval Academy and the RCA Institute of Electronics. He served on PT boats in World War II and was a Japanese prisoner of war in Manila.

Volk Made Sales Manager

Michiana Products Corp., Michigan City, Ind., has announced that James W. Volk has been made sales manager of their Steel Fabricating Division. The company makes a wide range of farm implements, heavy weldments, road graders, oil filters, fuel tanks and heat- and corrosion-resistant castings. Mr. Volk has served in the sales department of the division since 1949. He is a graduate of the University of Michigan and now makes his home in Long Beach, Ind., where he is active in community affairs.

Barnett Made Assistant Manager

Orville T. Barnett has been promoted to assistant manager of the metals research department of Armour Research Foundation of Illinois Institute of Technology, Chicago.

One of Mr. Barnett's responsibilities will be to help develop projects for new areas of research, according to Robert A. Lubker, department manager.

Dr. Donald J. McPherson, who was appointed assistant manager of the metals department in May, will concentrate on increasing the technical competence of the department and directing its personnel recruiting program, Lubker said.

A 1933 graduate of Illinois Tech, Mr. Barnett joined the Foundation in April 1954 as supervisor of welding research in the metals research department. He had been regional sales manager of the A. O. Smith Corp., Chicago, for the previous two years.

An expert in the field of welding and metallurgy, Mr. Barnett spent 2 years with the Carnegie-Illinois Steel Corp., Chicago; 4 years as engineer with Black, Sivalls and Bryson, Inc., Oklahoma City, and 11 years as district manager in Pittsburgh and New York for the Metal and Thermit Corp.

A member of the AMERICAN WELDING SOCIETY and the American Society for Metals, Mr. Barnett has written more than 100 articles for publication in the metallurgy field. He, his wife and two children reside at 8911 S. Cregier Ave.

Walsh Appointed Sales Engineer

John P. Walsh, formerly welding inspector and engineer for Foster Wheeler Corp., has been appointed sales engineer for General Ceramics' Pyrotone Welding Backing Rings.

In his new capacity in the General Ceramics Corp.'s Chemical Equipment Div., Mr. Walsh will handle sales and service of pyrotone rings. He will be located at Keasbey, N. J.

MacCutcheon Joins ONR

E. M. MacCutcheon has joined the Office of Naval Research as Coordinator of Vehicles Development. ONR advises that vehicles include ships, marine craft and piloted aircraft. Navy-wide coordination of development is a new function in the Office of Naval Research.

Mr. MacCutcheon graduated from Webb Institute of Naval Architecture where he received his Bachelor of Science degree in 1937. Following a short stay with the New York Shipbuilding Corp., he joined the former Bureau of Marine Inspection and Navigation in 1938 and remained with it when it became the office of Merchant Marine Safety of the U. S. Coast Guard in 1942. Following a period of general naval architectural duties, Mr. MacCutcheon was assigned to study the structural failures of the welded ships in 1943. He served on the numerous research advisory committees working on the ship failure problem and initiated many of the improvements in structural design details and fabrication techniques which were adopted in the ship construction during World War II. During much of this period Mr. MacCutcheon served as Lieutenant Commander (T) of the U. S. Coast Guard Reserve. In 1948 he joined the staff of the David Taylor Model Basin where he was the Head of the Materials and Statics Section of the Structural Mechanics Laboratory. Before joining the Office of Naval Research he was Research Coordinator in Naval Architecture in the Bureau of Ships, Navy Department.

Mr. MacCutcheon is a past-chairman of the Washington section of the AMERICAN WELDING SOCIETY and is current vice-chairman of the Chesapeake section of the Society of Naval Architects and Marine Engineers.

Swan Appointed Research Director

The appointment of David Swan as Director of Research of Metals Research Laboratories, Electro Metallurgical Co., a Division of Union Carbide and Carbon Corp., has been announced by A. L. Foscue, president of Electro-Metallurgical Co.

David Swan

Mr. Swan has been with Union Carbide since 1946 when he joined the Electromet Research Laboratories in Niagara Falls. In 1947 he was transferred to the New York offices of Electro Metallurgical Co. as research engineer. He moved back to Niagara Falls in 1952 when he was appointed Assistant Director of Research for the Laboratories. Mr. Swan will continue to be located at Niagara Falls, N. Y.

His early research work was concerned principally with the metallurgy and techniques of welding and cutting and with special studies of the production and uses of the various ferro alloys and metals employed in making steel and cast iron. In the capacity of Assistant Director of Research he had the responsibility in Niagara Falls for carrying out of the entire research program of the Laboratories.

50-ton crane becomes 85-ton crane
with no increase in size

United States Steel's Edgar Thomson Works in Braddock, Pennsylvania, needed new and heftier crane equipment to handle larger ladles. One requirement was four new crane trolleys which were to operate on the same bridges, if possible, and in exactly the same clearances as before.

The trolleys had to be stronger but no larger than before; so ordinary steel wouldn't do. Needed, was a steel of *exceptional strength* which could be *welded easily*. Lots of alloy steels could have met the strength requirements; but USS "T-1" Steel was the *only* steel that could supply not only the required strength, but good weldability as well.

"T-1" Steel plate—in ¾" and 1" thicknesses—was used in box girders and lateral stiffener plates of the trolleys. This change increased the crane capacity from 50 to 85 tons with no increase in size.

The structure was welded with AWS E12015 electrodes. It was as easy as welding carbon steel. No stress relief was needed. And the welds developed the full yield strength of the steel: 90,000 psi. minimum.

Remember this story when you must weld very high strength parts —parts that must operate at temperatures as high as 900°F. or as low as 40°F. below zero, parts that must withstand tremendous impact abuse, abrasion or tensile stress. Then consider USS "T-1" Constructional Alloy Steel. For full particulars write: United States Steel, Room 4773, Pittsburgh 30, Pa.

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USS "T-1" CONSTRUCTIONAL ALLOY STEEL

USS

UNITED STATES STEEL

Mr. Swan has served on a number of metallurgical advisory committees, and is the author of many papers in the field of metallurgy and welding. Among the technical societies of which he is a member are the American Society for Metals, AMERICAN WELDING SOCIETY and the American Institute of Mining and Metallurgical Engineers.

Mr. Swan was born in Rutherford, N. J., in 1920. He was graduated from Rensselaer Polytechnic Institute in 1940 where he received the degree of Bachelor of Science in Metallurgical Engineering.

Scott Appointed

Herbert J. Scott, formerly a Nelson Stud Welding field engineer in New York, St. Louis and Atlanta territories, has been named construction specialist in the Chicago area for the Nelson Stud Welding Division of Gregory Industries, Inc.

Scott will devote his entire efforts to working with architects, engineers, contractors and building material firms in the development of fastening designs and procedures, according to Robert C. Friedly, Nelson branch manager. Its midwestern headquarters and warehouse are located at 6556 West Higgins Road, Chicago.

Melvin O. Monsler

Monsler Promoted

Melvin O. Monsler, general manager of the welding equipment division of the Harnischfeger Corp., Milwaukee, Wis., has been appointed a member of the company's executive committee.

Mr. Monsler became general manager of the welding equipment division in 1953. Before that, he was sales manager for the division for two years. He started with Harnischfeger Corp. in 1937 as a welder in the fabricating shop. Mr. Monsler is a member of the AMERICAN WELDING SOCIETY.

Sterling C. Nichols

Nichols Appointed

The Steel Fabricators Co. of Cleveland, Ohio, has announced the appointment of Sterling C. Nichols as general sales manager effective July 1, 1955.

Since 1949 Mr. Nichols operated in the capacity of sales representative for the same company. In prior years he was also connected with the Warner and Swasey Co. and The Glidden Co. of Cleveland.

Mr. Nichols is a member of the AMERICAN WELDING SOCIETY.

Loup Made Director

Progressive Welder Sales Co. announces the appointment of Ronald L. Loup as director of the Development Engineering Division.

Ronald L. Loup

Mr. Loup, a graduate of General Motors Institute, has a wide background in engineering and process development. After serving in the Navy during World War II, he joined a large truck manufacturer as a tool and hydraulics engineer. His experience includes application engineering, works manager and chief engineer for two other prominent companies.

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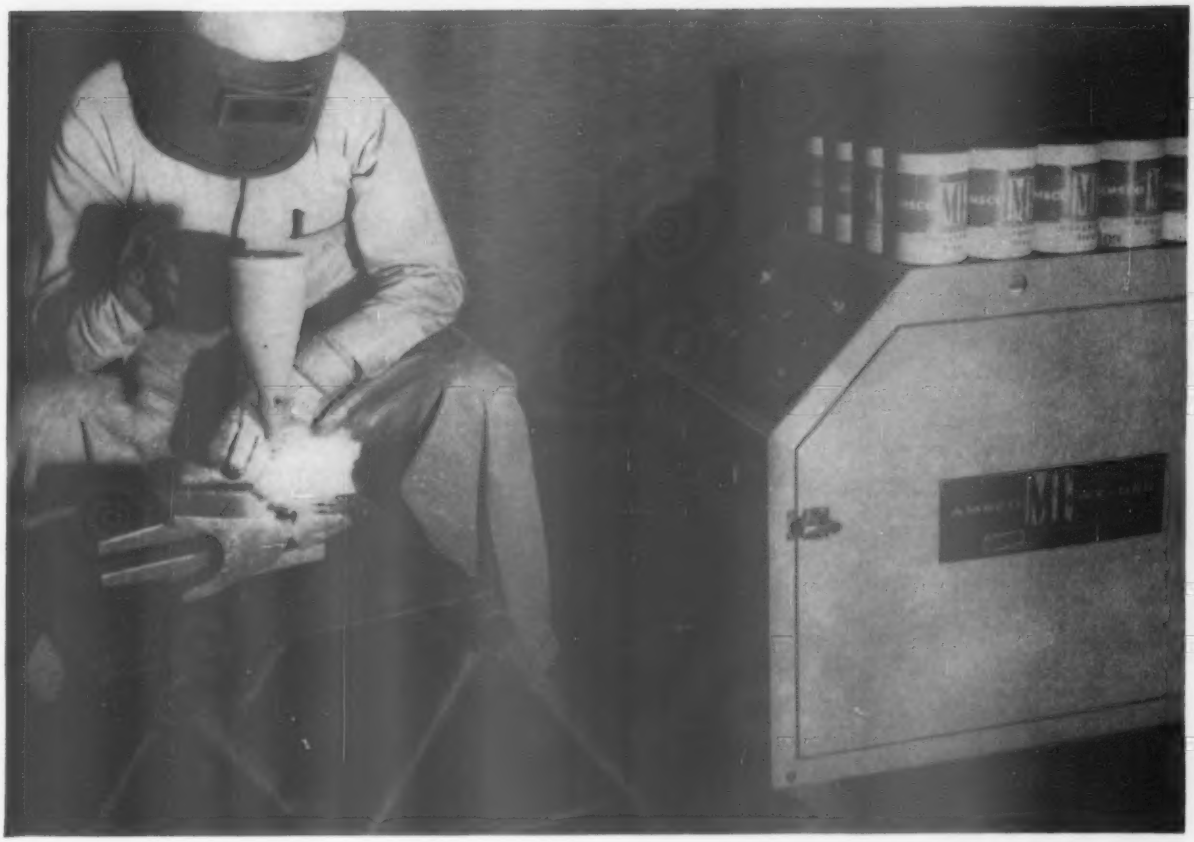


Welder is shown welding a "wear-sharp" repointer to the shank of a dipper tooth using the Amsco MF and flux.

HARDFACE WITH THE AMSCO® MF

for manual flexibility . . . plus machine speed and accuracy

The Amsco MF combines the visibility and craftsmanship of hand welding with the automatic advantages of machine work. Speed of hardfacing increases because the Amsco MF uses small-diameter electrode and high-current densities which allow the operator to maintain a high deposit rate. The electrode feed is continuous—and automatically regulated—to maintain a constant arc. Thus, the machine automatically *compensates* for operator movement or an irregular welding surface.

Cost of deposited metal is less! The Amsco MF uses coiled, bare mild steel electrode. It feeds through the flux hopper (the cone). There it is magnetically coated with your choice of manganese steel build-up or hardfacing alloy which is carried in the flux. You coat your electrode as you weld at considerable savings in deposit cost.

The machine is portable. It plugs into any standard welding unit, and requires no special setup. See a demonstration of the Amsco MF's speed, quality of weld and uniform deposit. Try it yourself and discover how easy it is to operate. Your Amsco Distributor is ready to show it to you now. Welding products are distributed in Canada by Canadian Liquid Air Co., Ltd.

make your Amsco Distributor HARDFACING HEADQUARTERS

AMERICAN Brake Shoe COMPANY

AMERICAN MANGANESE STEEL DIVISION
Chicago Heights, Ill.

CHECK THESE EXCLUSIVE ADVANTAGES of the NEW

HI-AMP HOLDER

-and You'll Wonder Why You're Not Using them Now!

- Spring completely enclosed and insulated. Cannot be knocked or shorted out.
- Spring adjustment screw for ease of replacement and adjustment to rod size.
- Handle cannot absorb moisture—withstands higher temperatures.
- Tip Insulator reversible for longer service life.
- Low Trigger for ease of rod-relief cuts down operator fatigue.
- Slender rod griping tonges to get in tight places.

Sold only through Welding Supply Distributors in the U. S. and Canada.

WAGNER MFG. CO.
350 W. 1st SOUTH ST.
JACKSON, MISSOURI

Weld with Wagner

Chang Joins G. E.

F. P. Wilson, Jr., manager of the Materials and Processes Laboratory, announces the appointment of Wen Hsiang Chang, formerly of Hunan, China, who recently joined the Materials and Processes Laboratory of the General Electric Co.'s Large Steam Turbine-Generator Department, Schenectady, N. Y., as an applied research engineer. He is currently studying brazing filler metals for elevated temperature service, and the effects of ultrasonics on brazed joints.

Dr. Chang received his Ph.D. degree from Rensselaer Polytechnic Institute, Troy, N. Y., last February. He received his Bachelor of Science degree in Metallurgy from National Hunan University, China, in 1946 and his Master's degree in Metallurgy from the Missouri School of Mines, Rolla, Mo., in 1950. He is a member of the scientific honorary society, Sigma Xi; the chemical honorary society, Phi Lambda Epsilon; the American Society of Metals; the AMERICAN WELDING SOCIETY; and the British Institute of Metals.

Dr. Chang lives at 920 Wendell Ave., Schenectady.

Wen Hsiang Chang

Attention, Authors!

Please keep in mind that to assure consideration for the 1956 National Spring Meeting Program, your filled-in Author's Abstract Form must reach AWS headquarters not later than October 15, 1955.

1. WORN TOOTH

2. TRIM WITH TORCH

3. SELECT WING-DING

4. WELD AROUND EDGES

reduce welding time to a minimum—

REBUILD WORN TEETH

...the modern...quick...easy way with—

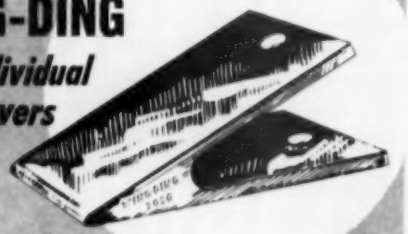
MANGANAL

T.M. Reg. U.S. Pat. Off.

CAST 11%-14% MANGANESE-NICKEL STEEL

WING-DING

Individual Slip-Overs



- Replace worn metal faster.
- Eliminate hard-to-make welds in deep Vee.
- Plug welds, through holes in wings, give extra strength.
- Nine individual casting sizes to fit every size tooth.
- For stronger welds attach with MANGANAL FLO-KOTE, SPECIAL TITE-KOTE or BARE WELDING ELECTRODES. Weld deposits easily cut with torch when tooth is repointed again.

STULZ-SICKLES CO.

SOLE PRODUCERS 92 N. J. RAILROAD AVE. NEWARK, N. J.

NEAREST DISTRIBUTOR UPON REQUEST

OBITUARY

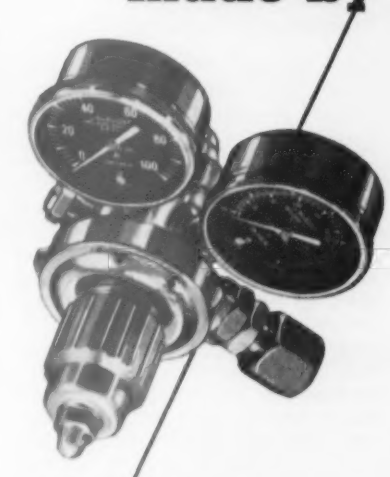
Christopher E. Loos

Christopher Earle Loos, assistant metallurgical engineer, structural, plate and high strength steels, United States Steel Corp., Pittsburgh, Pa., passed away on July 30, 1955. A graduate of Lehigh University and member of Tau Beta Pi, honorary engineering society, Mr. Loos was associated with United States Steel for 40 years. He began his career with American Bridge Co. In 1939 became manager of the Structural and Plate Bureau of the then Carnegie-Illinois Steel Corp., and in 1947 assistant metallurgical engineer, structural, plate and high strength steels, the position he held until his death.

In addition to his membership in the AMERICAN WELDING SOCIETY for a number of years, other society affiliations were American Society for Metals, American Railway Engineering Association and American Society for Testing Materials. A member of ASTM since 1940, active since 1944 and chairman of Subcommittee II of Committee A-1 on Steel since 1948, in June 1955 Mr. Loos received the ASTM Award of Merit in recognition of his significant leadership in improving specifications requirements for structural steels.

they choose the very finest made by

The beautiful new DC-7 UNITED MAINLINER now placed into transcontinental service by UNITED AIR LINES represents the best money can buy; every minute detail for the travelers' safety, comfort, pleasure and swift transportation has been incorporated into this speedy plane. Its cost is about $1,750,000. Each individual turbo-compound engine, and there are four of them, costs some $65,000.00 and they offer the traveler a cruising speed of 365 mph. We are proud, indeed, that our company's regulators were selected a component of such an outstanding selection of construction parts as comprise this marvelous product of the engineering and construction genius of the Douglas Aircraft Company. You, too, are fully justified to place your confidence in these fine pressure regulators which today serve the most critical buyers.



it's free...

would you like us to mail you the full details of design and construction features described and color illustrated in the 44 page regulator brochure, form No. 4 . . . it's yours for the asking.

NATIONAL welding equipment company... 218 fremont street san francisco 5 california

539 DEPT 143

NEW PRODUCTS

Bronze Rods

The All-State Welding Alloys Co., Inc., White Plains, N. Y., announces that the company is now ready to supply flux-coated low-fuming bronze in 36-in. lengths.

Neither the alloy nor the flux is new. It is the combination that should be noted.

The alloy is applicable at 1650° F and its deposits develop a tensile strength of 60,000 psi. It is for all-around use in repairs, reclamation and assembly wherever bronze can be used.

The flux is that used on All-State's nickel-silver brazing rods. It does not char or leave carbon—does not blister or burn back up the rod—does not attract moisture. It is designed for efficient brazing and to cause the bronze to flow out more freely and smoothly. Its effectiveness does not deteriorate with repeated wetting and drying according th the manufacturer.

Complete information may be had by writing directly to company at above address.

Temperature Indicators

The Tempil® Corp. of New York announces that the available range of Tempil® products has been expanded considerably during the last few months. New temperature ratings have been added in the important 400 to 500° F. interval to permit close temperature control.

Improvements have been made both in packaging and labeling. Tempilstiks® are now packaged in transparent, unbreakable tubes, and new easy to read labels designate both Fahrenheit and Centrigrade degrees. The outer package too has been redesigned—a bright maroon carton for Tempilstiks® and Tempilaq®, with the product name in distinctive white type to facilitate identification and stock keeping on the distributor's shelves.

For complete information, write to Tempil® Corp., 132 West 22nd St., New York 11, N. Y.

Resistance Welding Control

A new line of resistance welding controls featuring printed circuits and a weld-safe circuit for the protection of equipment and work in process is available from the Westinghouse Electric Corp. Circuit components and tubes have been reduced to the minimum number necessary for proper functioning. This circuit simplification combines with the use of printed circuits to reduce panel weight by 30%.

The weld timer and sequencing circuit is designed to lock out welding current should tube failure occur at any time.

All component locations and ratings are printed on the front of the panel to facilitate inspection and servicing. Components can be removed or replaced with conventional soldering methods.

For further information on this new line of controls, write Westinghouse Electric Corp., P. O. Box 2099, Pittsburgh 30, Pa.

Hard-Facing Powder

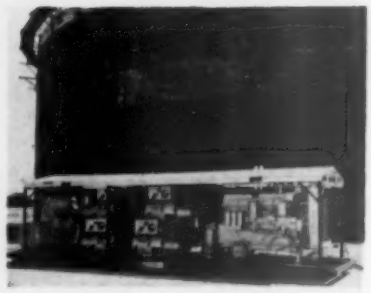
A new series of Colmonoy alloy powders which produce improved deposit efficiency when used in spraywelded hard-facing applications is now available from Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

Improved manufacturing techniques at Wall Colomonoy have resulted in powders of the nickel-chromium-boron alloys, Colmonoy Nos. 4, 5 and 6, having as much as 10% improvement in deposit efficiency. Better deposit efficiency means less powder is required to produce a given thickness of protective coating as sprayed on the workpiece.

Complete information may be had by writing to Wall-Colmonoy at above address.

Power Unit

Large fuel savings are claimed by the use of the welding unit shown, rather than individual gasoline engine-driven welders. The unit consists of one Caterpillar DI3000 engine connected to a jack shaft which, by means of V-belt drives, powers eight 400-amp Lincoln welders. Attached to the end of the jack shaft with a clutch is a 182-



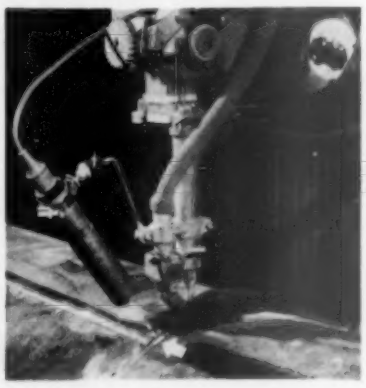
cfm air compressor. Power is steady and supposedly, it is impossible for the welders to tell by means of their arc when the air compressor comes on and off.

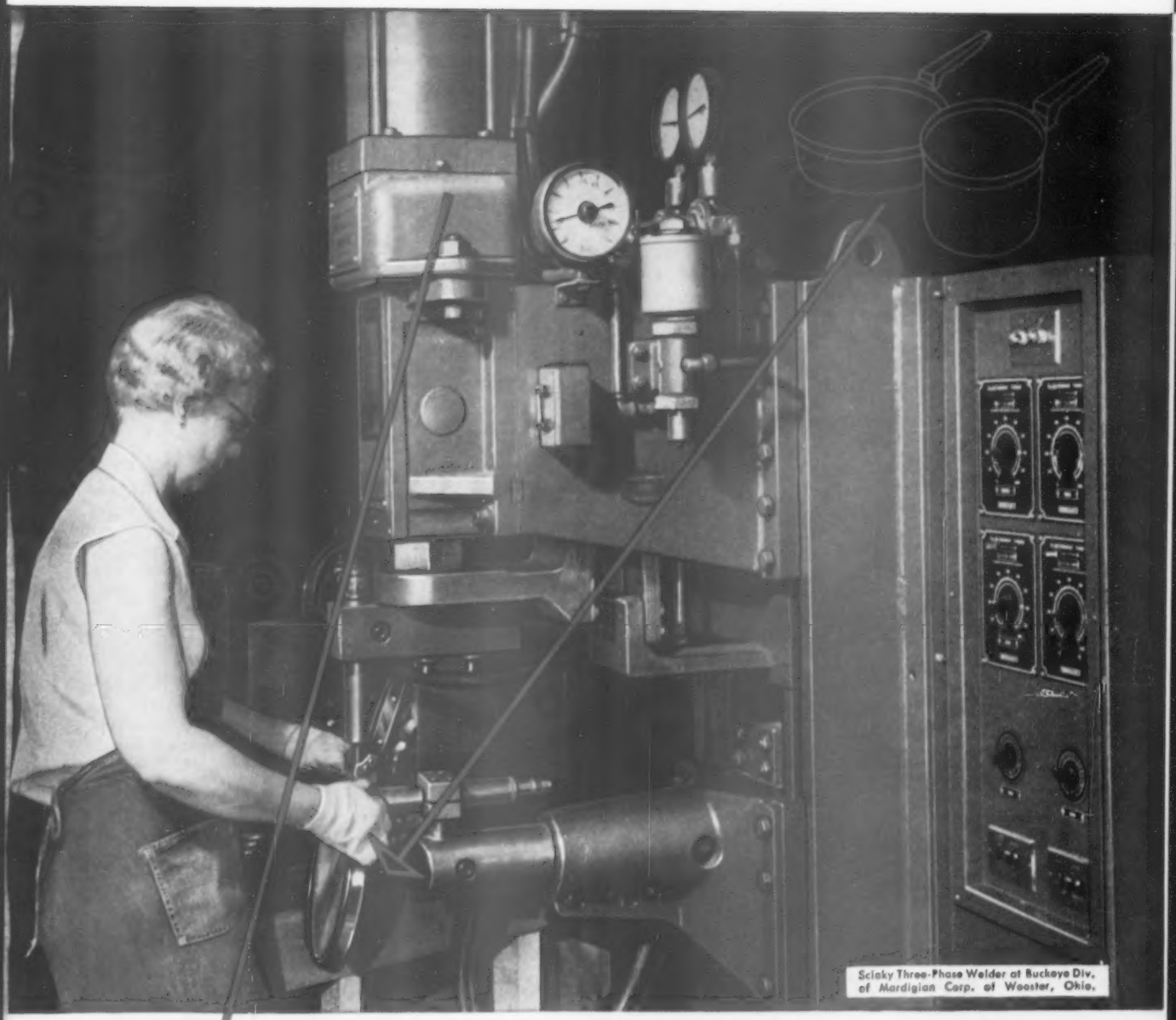
The unit was made for the Sapulpa Tank Co. by McCormick Machinery Co., Tulsa, Okla.

For further information, write to Lincoln Electric Co., Cleveland, Ohio.

Welding Guide Light

The Jimmie Jones Company o Tulsa, Okla., announces the availability of an inexpensive automatic welding guide light intended to eliminate costly repairs in off-center submerged arc welds caused by inadequate guiding methods. The projected spot of light gives the operator a definite reference point for the accurate guiding of the submerged welding head. In use, the automatic welding guide light is rigidly attached to the welding head and moves with it. The bright "in line" spot is projected either in the weld groove or on a parallel edge. With the spot in sharp focus the light serves as an indicator of the hidden weld position and also indicates the height of the contact jaws above the work, an important factor in weld voltage control.





Sciaky Three-Phase Welder at Buckeye Div. of Mardigian Corp. of Wooster, Ohio.

PRODUCTION JUMPS 375%...

Costs Cut Sharply with Sciaky Patented Three-Phase Welders

FACTS ABOUT SCIAKY PATENTED THREE-PHASE

	SINGLE-PHASE	SCIAKY THREE-PHASE	SAVINGS
TRANSFORMER RATING	250 KVA	100 KVA	150 KVA
WELDING KVA DEMAND	650 KVA	325 KVA	325 KVA
LINE AMPS PER CONDUCTOR 440 V.	1,476 A.	430 A.	1,046 A.
POWER FACTOR	30%	85%	Greatly Improved
INSTALLATION COST—EST.	$10,500	$5,250	$5,250

Buckeye, with an enviable 52 year record of manufacturing, uses Sciaky patented Three-Phase Balanced Load, High Power Factor **resistance** welders extensively in fabricating high quality aluminum kitchenware.

Standard Sciaky Three-Phase Welders increased production 375% over riveting in joining a variety of handle mounting brackets to different size pans. Even beyond the savings in costs of rivets and related tooling, Sciaky Balanced Load Three-Phase with 85% power factor (compared to 30% for conventional single phase) and a 50% reduction in power demand, is far less expensive to operate than conventional single phase *unbalanced load* welders. Sciaky Three-Phase readily solves power problems, and further, installation costs are estimated at only half of single phase installation cost.

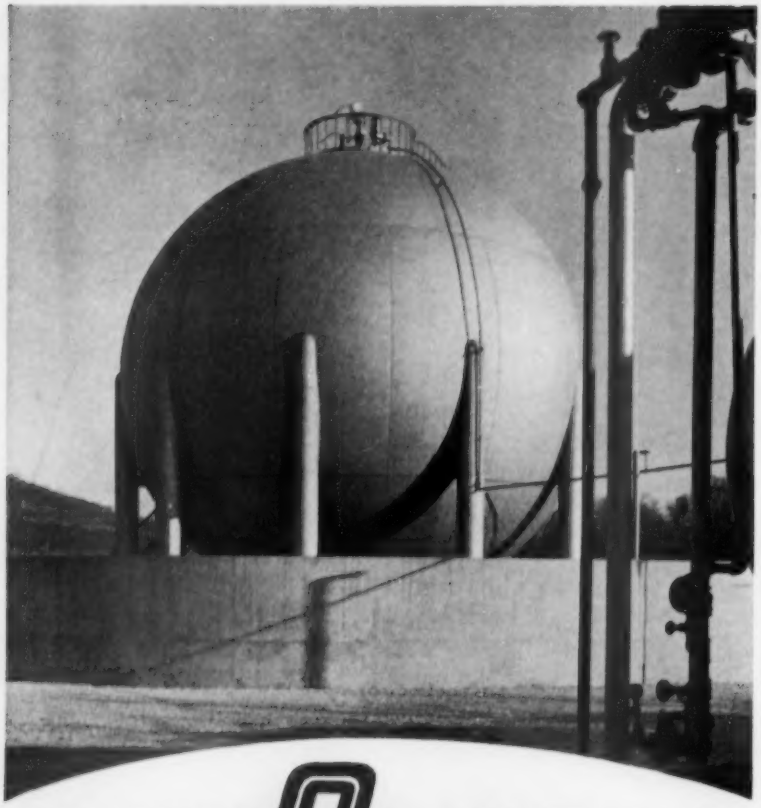
Write today for "Resistance Welding at Work", Vol. 4 - No. 2. Read the complete details of Buckeye's impressive application of Sciaky basic thinking—welders designed to do *more useful work* at *lowest operating cost* with *maximum reliability.*

Largest Manufacturers of Electric Resistance Welding Machines in the World

SCIAKY

Sciaky Bros., 4919 West 67th Street, Chicago 38, Illinois

For speed, economy and dependability when welding low-alloy steels...



WELD WITH ARCOS

LOW HYDROGEN ELECTRODES

When welds *must be strong*—as in the Hortensphere* pictured above—ARCOS Low Hydrogen Electrodes will do the job. Usable in all positions, they produce uniformly high quality welds to meet the most rigid inspection standards. Time and money will be saved by eliminating preheat and by avoiding costly repair welds. ARCOS CORPORATION, 1500 South 50th St., Philadelphia 43, Pa.

*Trademark registered by Chicago Bridge & Iron Co.

For additional information, write to The Jimmie Jones Co., 1016 East Fourth St., Tulsa, Okla.

Toggle Clamps

Erico Products announce the availability of their Caddy P-5, 10,000-lb (horizontal) pressure Toggle Clamp.

The P-5 has all of the regular features of Caddy Toggle Clamps and has a $2^{15}/_{16}$-in. stroke.

For further information, write to Erico Products, Inc., 2070 East 61st Place, Cleveland 3, Ohio.

Resistance Welder

Sciaky Bros., Inc., 4915 West 67th St., Chicago, Ill., announce the new design of a standard, air-operated, single-phase EPDF Dial Feed Rotary Indexing Welding Machine. This new welder is being used in high production by a nationally known manufacturer of automobile bumper guards.

This machine is capable of producing 1000 completed assemblies per 50 minute hour—more than doubling the production rate of previous fabricating process with obsolete, conventional resistance-welding equipment.

For more complete information of the Sciaky Dial Feed, write to Sciaky, Dept. M-3 at the Chicago address requesting Bulletin 319-12.

Flux-Coated Rod

Those taking deliveries of bronze rod in shipments of 500 lb or over can now buy flux for it *on the rod*.

Custom coating services available

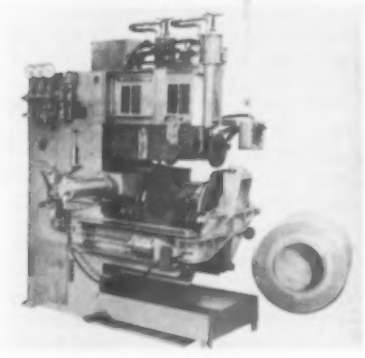
from All-State Welding Alloys Co., Inc., 249–255 Ferris Ave., White Plains, N. Y., have now been extended so that $^1/_8$-, $^5/_{16}$- and $^1/_4$-in. rods 36 in. long can be flux coated. The service is also available for $^3/_{32}$-in. rods, but in 18-in. lengths only.

The flux is anhydrous and does not attract moisture. There is no charring or carbon deposits. The flux does not burn back up the rod and does not blister. Cleansing action of the flux is rapid, positive and smooth. It enhances the brazing action.

For additional information, write directly to All-State Welding Alloys Co. at above address.

Roll Spot Welder

Roll spot welding maintains production line speed in the assembly of a clothes dryer drum for a large appliance manufacturer.



Taylor-Winfield resistance seam welder makes two "stitch" seams of separated spot welds as the drum rotates between the welding wheels. This permits very closely placed spot welds and produces uniform welds due to the repetitive welding operation.

The welder provides convenient loading of parts: a cylindrical shell and two heads of sheet steel. These are clamped into position and held firmly in alignment while the drum rotates.

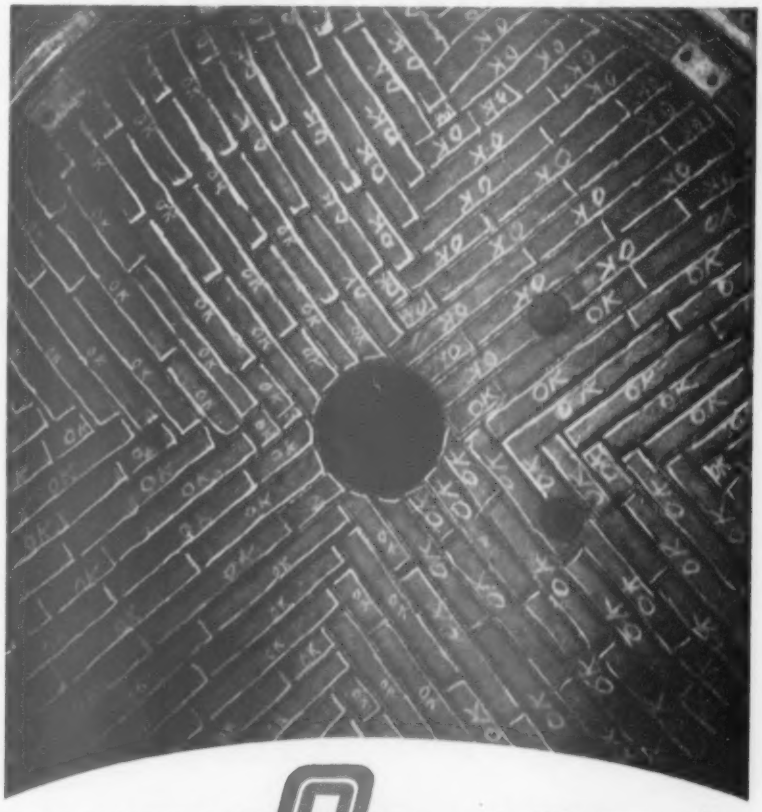
A series welding circuit makes two circumferential rows of spot welds, one at each end of the drum. After welding, the rotating mounting of inside wheels lowers the entire assembly on support rollers. This permits the operator to remove the drum from the welder easily.

For further information, write to Taylor-Winfield Corp., Warren, Ohio.

Insulation for Welding Equipment

Costly "Shorts" (shorting out of equipment) that plague the electric spot welder and result in poor welds, work stoppages and part rejects have

How to get the "OK" on stainless welds . . . time after time

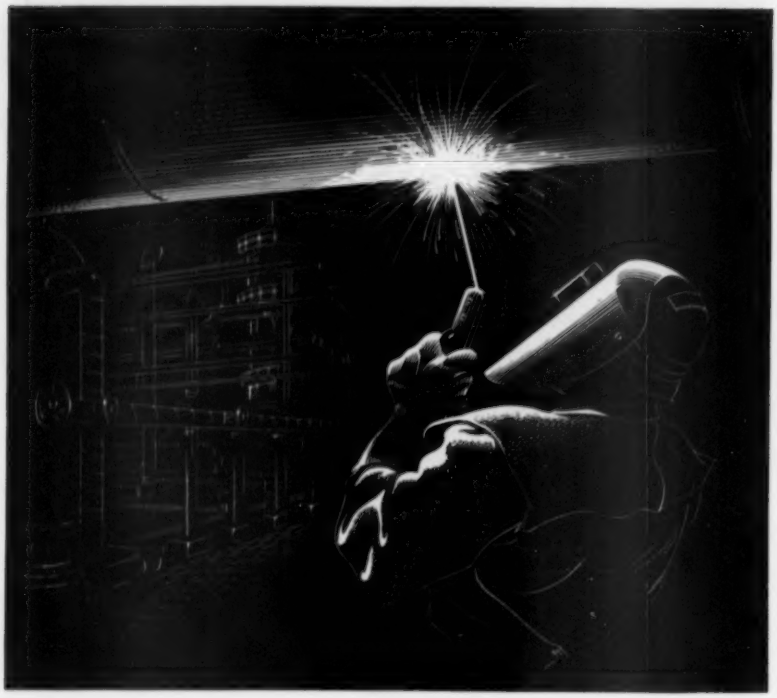


WELD WITH ARCOS

STAINLESS ELECTRODES

On weld after weld—such as in this refinery tower lining which must resist intense corrosion—Arcos quality controlled electrodes will give you the "right" weld metal . . . easily deposited. If you are looking for sound, low cost, long-life welds—you can rely on Arcos *ELECTROPAKED* Electrodes to produce unquestioned "OK's" time after time. ARCOS CORPORATION, 1500 South 50th Street, Philadelphia 43, Pa.

New ARCALOY
502 LIME ELECTRODES
for x-ray quality welds
in 4 to 6% Chrome Steels



New Arcaloy 502 lime electrodes produce welds of required x-ray quality in 4 to 6% chrome steels as required for high temperature, high pressure services. Arcaloy 502 electrodes have a new lime, low hydrogen type coating, *a coating that will not fingernail*, eliminates underbead cracking and provides a basic slag with a scavenging action that consumes impurities.

The New Arcaloy 502 lime electrodes have excellent weldability *in all positions*, with an arc action smooth and stable, an easy-to-control weld metal and slag. Arcaloy 502 electrodes conform to A.W.S. A5.4 and A.S.T.M. A298-55T Specifications, Grade E502-15. Try the New Arcaloy 502 electrodes for x-ray quality welds in your high temperature, high pressure applications. Contact your Alloy Rods Distributor or write the plant for all the facts.

Alloy Rods Co.

General Offices and Plant • York 3, Penna.
Pacific Coast Sales Offices and Plant
El Segundo, California

no finer electrodes made . . . anywhere

reportedly been greatly reduced by the introduction of an entirely new kind of plastic insulation for welding equipment.

The new insulator, called the Amazi Welding Insulation, is shown in the photo (bottom) in near perfect condition after 14 hours of welding. A conventional method of insulation (top) needs replacement after one hour.

Application of the new insulator to welding points, point holders and other trouble spots—where metal being welded is apt to come in contact with the equipment—results in a smooth, nonpeeling, plastic surface of cement-like hardness that is not brittle and does not conduct electricity.

Write for additional information to Amazi Reliner Corp., 520 No. Edgeworth, Royal Oak, Mich.

Tractor Welds

The Unitow Industrial Tractor, shown in the photograph, was designed to provide a mobile self-powered welding unit for installations in which welding applications occur at widely separate points. By traveling directly to the job and being ready to weld without waiting for electricians to hook up power lines, the unit saves hours of time. Since it is capable of pulling or pushing up to 70 tons, it can tow construction materials directly to the job.

Both the tractor and the 300- or 400-amp Lincoln generator are powered by an International Harvester Silver Diamond engine. A power take-off mounted on top of the transmission provides power for the generator without the use of belts. Besides the standard welder tractor unit, an all-weather cab, acetylene and oxygen tank bracket

with cable reel, snowplow and rotary sweeper boom may be added as extra equipment. Since it is only 53 in. wide, 138 in. long and 65 in. high and has a turning radius of 118 in., the tractor is capable of navigating narrow aisles, low doorways and crowded docks.

Unitow Industrial Tractors are manufactured by United Boiler and Foundry Co. in Hammond, Ind.

Welding Head

A new welding head designated as model WHD 5 has been developed by Ewald Instruments to permit reliable spot welding of subminiature parts down to 0.0003-in. thickness.

The model WHD 5 has a rigid welding arm with a moving mass of less than $^1/_4$ oz mounted in radial ball bearings. The arm is balanced in itself, so that the pressure on the electrode is due only to the pressure exerted by a leaf spring. This is claimed to result in exceptionally fast follow-up forging action.

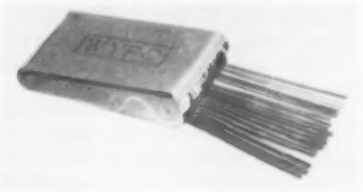
Pressure adjustment is affected by moving a sliding fulcrum on the leaf spring with the pressure indicated on a scale calibrated in ounces and pounds. (Ranges available from $^1/_2$ oz to 3 lb.)

For complete information, write to: Ewald Instruments, 93 Nassau St., New York 38, N. Y.

Tip Cleaners

Designed to bring greater convenience to welders, a new Master Set of Wypo Tip Cleaners has recently been developed by Maitlen & Benson, Inc. The new set contains all sizes of cleaners found in both the Standard Set and Jumbo Set, thereby enabling the welder to have all 21 sizes of tip cleaners at his finger tips.

Development of this new Master Set was made at the request of Government buying offices, according to An-



for SOUND WELDS

with OUTSTANDING PHYSICALS

use NEW Bronze-Arc C

PHOSPHOR BRONZE ELECTRODES

Another "first of its kind" development of Alloy Rods Company research brings an entirely new phosphor bronze electrode—Bronze-Arc C. Incorporating a unique low hydrogen type coating, Bronze-Arc C electrodes have demonstrated advantages . . . porosity-free deposits, all-position welding, smooth easy flowing arc characteristics, easy slag removal and outstanding physical properties.

Typical Physical Properties of Bronze-Arc C Electrodes

Tensile Strength p.s.i.	58,000 to 65,000
Yield Strength p.s.i.	30,000 to 37,000
% Elongation in 2" ga.	42% to 48%
Hardness, Rockwell B	72 to 78
Face Bend	180°
Root Bend	180°

Bronze-Arc C conforms to A.W.S.—A.S.T.M. Specification No. B-225-53T, Classification E CuSn-C.

Write today for complete information on new Bronze-Arc C electrodes—the electrodes designed especially for high strength, X-Ray quality welds.

Alloy Rods Co.

General Offices and Plant • York 3, Pa.
Pacific Coast Sales Office and Plant
El Segundo, Calif.

no finer electrodes made . . . anywhere

TWIN POCKETSCOPE

by Waterman

Size:
12" x 6" x 7"
16¼ Pounds

MODEL S-15-A

TWO IDENTICAL INDEPENDENT OSCILLOSCOPES WITH COMMON TIME BASE

ANOTHER EXAMPLE OF Waterman PIONEERING...

The WATERMAN TWIN POCKETSCOPE, model S-15-A, presents a new concept in multiple trace oscilloscopy with independent vertical channels each having a sensitivity of 10 millivolts rms/inch, and a response within −2 db from DC to 200 KC—a pulse rise time of 3 microseconds. These features combined with the provisions for intensity modulating either, or both, traces, results in greater flexibility. The sweep generator is operated either in the repetitive or triggered mode from 0.5 cycles to 50 KC with synchronization polarity optional. All attenuators and gain controls are of the non-frequency discriminating type. Remember that portability has not been overlooked! The amazing small size of the S-15-A tips the scales of opinion heavily in its favor. Imagine, all of these essential characteristics in an instrument weighing only 16¼ lbs. You can carry it to any job, anywhere!

WATERMAN PRODUCTS CO., INC.

PHILADELPHIA 25, PA.
CABLE ADDRESS: POKETSCOPE

WATERMAN PRODUCTS INCLUDE

S-4-C SAR PULSESCOPE®
S-5-A LAB PULSESCOPE
S-6-A BROADBAND PULSESCOPE
S-11-A INDUSTRIAL POCKETSCOPE®
S-12-B JANized RAKSCOPE®
S-14-A HIGH GAIN POCKETSCOPE
S-14-B WIDE BAND POCKETSCOPE
S-15-A TWIN TUBE POCKETSCOPE
RAYONIC® Cathode Ray Tubes
and Other Associated Equipment

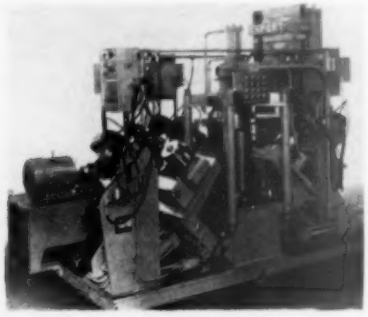
thony Ghio, general sales manager, and was therefore designed to meet the specifications of the Government and is now on the approved Government buying list.

Maitlen & Benson, Inc., will, of course, continue to manufacture both the Standard Set of 12, which cleans 27 drill sizes, Nos. 75 to 49, inclusive, and the Jumbo Set of 9, which cleans 19 drill sizes, Nos. 48 to 30, inclusive.

For full information, write the factory direct. Maitlen & Benson, Inc., are located at 1395 Obispo St., Long Beach 4, Calif.

Combination Welder

A new high-production welding machine that utilizes automation methods to combine assembly and argon shielded-arc welding operations has been designed and built by Expert Welding Machine Co., 17144 Mt. Eliott Ave., Detroit 12, Mich. One operator can assemble and weld two 8-in. diameter sheet metal fluid coupling parts at a rate of 300 finished assemblies per hour on one of the new machines.

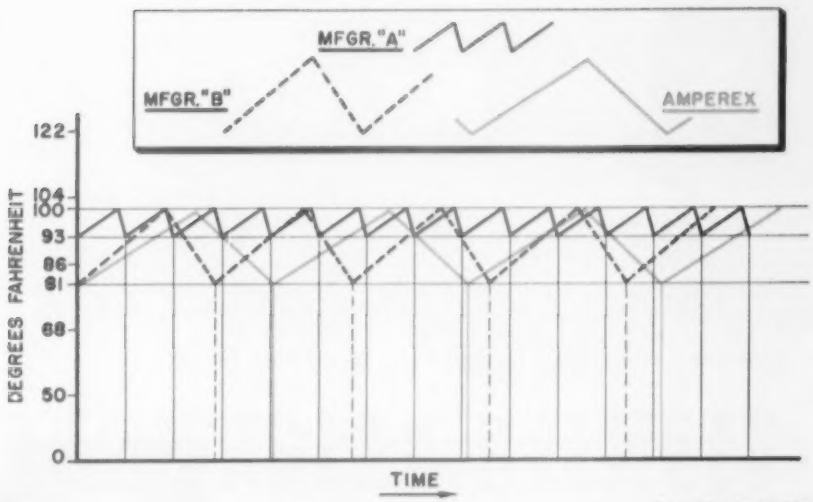


Called the Expert Triaxial Welder the machine consists of a special vertical hydraulic assembly press and three standard argon shielded-arc welding heads. These welding heads are positioned at 90-deg locations around the assembly press. High production rates are achieved by performing the welding operation on two fixtures while parts are being assembled in a third fixture by the press. To accomplish this, three automation devices transfer the fixtured and assembled part to the welding head, rotate the fixture and part at a speed of 90 in. per minute for the welding operation, and return the fixture and part to pressing position for unloading.

Hydraulically controlled pivoted fixtures act as automation devices to provide the required transfer and rotation movements. The three fixtures are pivoted at the base of the press. Individual hydraulic cylinders control the motion of the fixtures in and out of the press. Hydraulic motors rotate the

The PRACTICAL SOLUTION To Thermostatic Control of Ignitrons by Amperex®

THERMOSTAT OPERATION UNDER IDENTICAL SERVICE CONDITIONS



NOTE THAT THE AMPEREX THERMOSTATIC CONTROL GIVES SAME WATER SAVING SERVICE WITH MINIMAL SWITCHING. CUTS DOWN MAINTENANCE ON SOLENOID VALVES OR OTHER CONNECTED COMPONENTS.

RELATIVE NUMBER OF OPERATIONS	
A	72
B	32
AMPEREX	20

COMPARE the frequency of thermostatic operation of three ignitrons under the same load conditions, shown in chart above. The same "water-saver" efficiency was achieved in all three cases.

The advantages of thermostatic control are necessary in many cases. However, for practical reasons, the "water-saver" function should be fullfilled without unnecessary switching . . . and without unnecessary wear and tear on solenoid valves or circuit components. Unnecessary work imposed upon associated equipment usually results in high maintenance costs and/or service interruptions!

Field tests under actual severe load conditions have proven that the AMPEREX thermostatic control design is SIMPLE, PRACTICAL and DEPENDABLE.

Uses high-quality standard thermostats, electrically and mechanically interchangeable with the majority of other types.

AMPEREX
Thermostatically-Controlled Ignitrons are available in 3 types: 5551-A, 5552-A and 5553-B.

Other features of AMPEREX Ignitrons include the exclusive AMPEREX developed long-life ignitor made with new, refractory semi-conductor, detachable, heat-dissipating, heavy-duty anode connector and rugged stainless steel housing.

There's an AMPEREX distributor in all principal cities. Write direct to factory for data sheets and name of distributor nearest you.

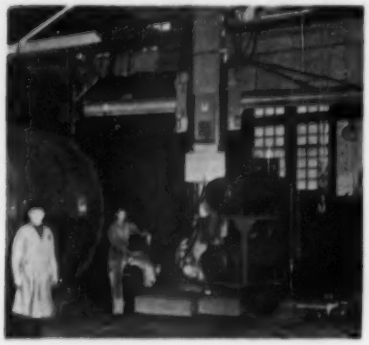
Amperex ELECTRONIC CORP.
230 Duffy Avenue, Hicksville, Long Island, N. Y.
In Canada: Rogers Majestic Electronics Ltd.
11-19 Brentcliffe Road, Leaside (Toronto 17)

assembled part and fixture as a unit during the welding operation.

For full information, write directly to company.

Versatile Welding Machine

The new welding machine shown in the accompanying photograph has been installed at the plant of the Boom Boiler and Welding Co., Cleveland,



Ohio. It has been manufactured by The C. B. Herrick Manufacturing Corp., and is said to provide maximum flexibility in applying submerged arc welding to weldments in a wide variety of size and shape. The boom-type welding machine is mounted on a rotor providing 360 deg of motorized rotation and on a carriage which travels on a special track 0–72 in. per minute.

A standard Lincoln Electric automatic head is mounted on the end of a ram which travels 12 ft with a speed range of 0 to 72 in. per minute. The ram can be adjusted vertically by motor from 2 to 12 ft. Travel speeds are indicated on the control panel and are controlled by limit switches to prevent overtravel. V-type wheels riding in V-machined ways guide both the vertical and ram travel.

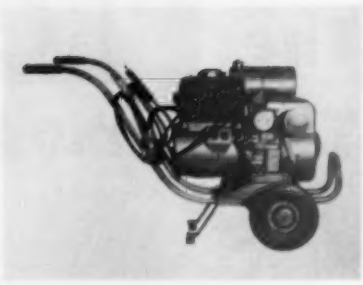
The machine is completely controlled from a pendant control which may be either carried by the operator or mounted on the working end of the ram.

For further information, write to Lincoln Electric Co., Cleveland 17, Ohio.

A-C Generator-Welder

A new, low-cost, portable a-c generator-welder combination weighing just 250 lb is announced by Royal Arc Industries, Inc., Chillicothe, Ill.

Designed as a portable source of a-c power, the unit combines the new air-cooled Onan 205 AJ-1M, 2500-w, 115-v, 60-cycle a-c electric generating plant with the Royal Arc Model 150AJ



transformer-type welder to become a versatile generator-welder "package" for construction, building and repair jobs.

As separate units, the generator or welder may be operated independently of the other—disconnect the welder and the generator becomes a portable a-c power plant—lift the welder free from the assembly and plug into any 110- or 220-v, single-phase, a-c current for repair and maintenance work of all kinds.

As a portable source of 60-cycle current, the combination is ideal for emergency use when commercial power is interrupted.

For complete information, write to Royal Arc Industries, Inc., Chillicothe, Ill.

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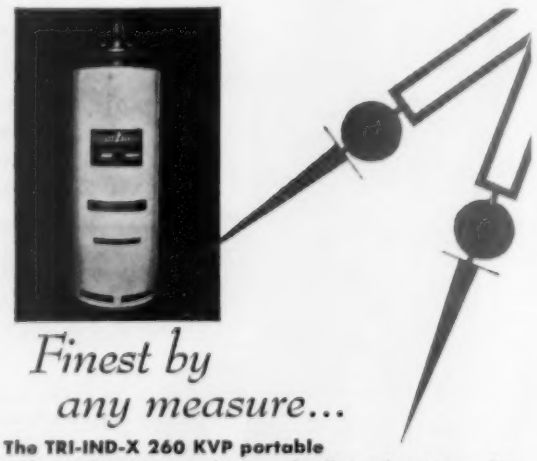

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NEW LITERATURE

Brazing Alloys

A folder describing a series of nickel-base alloys marketed by Coast Metals, Inc., of Little Ferry, N. J., is now available.

Furnished in powder form, these alloys are exposed to severe wear and corrosion. It is claimed that there is a great deal of interest in their use for high-temperature brazing, particularly in aircraft work.

For your copy, write directly to Coast Metals, Inc.

News Letter

Dix Engineering Co. in Lincoln Park, Mich. (just outside of Detroit), has inaugurated a new service to its customers, according to an announcement from Knowles B. Smith, vice-president.

The new service takes the form of a monthly "news letter," illustrated, which tells the story of interesting, instructive and at times entertaining instances of DixCo emergency services, including welding, engineering and "metallizing."

Each month DixCo will mail their stories to their friends and customers in industry. For your copy, write to Dix Engineering Co., Inc., 1415 Dix Road, Lincoln Park, Mich.

Three-Phase Bulletin

Sciaky Bros., Inc., 4915 West 67th St., Chicago, Ill., introduces the new bulletin *Three-Phase*—a Sciaky patented power-saving principle of operation.

The Three-Phase principle of operation was pioneered, invented, and patented by Sciaky. The use of electronics enables the Sciaky patented Three-Phase machines to draw a balanced current from all three phases of the supply line.

For more complete information on the Sciaky Three-Phase principle of operation, write to Public Relations Dept. L-2 at the Chicago address requesting *Three-Phase Bulletin 332-10*. For illustrated stories of typical applications of Three-Phase resistance welding, request free copies of "Resistance Welding at work," Vol. 4, #4; Vol. 4, #3; Vol. 4, #2; Vol. 3, #10; Vol. 3, #9; Vol. 3, #8 and Vol. 3, #7.

Booklet on Electron Microscopes

A new 8-page booklet titled "Questions and Answers on Electron Microscopes" is available gratis from the Research and Control Instruments Division, North American Philips Co., Inc., 750 South Fulton Ave., Mount Vernon, N. Y.

Text material was prepared specifically to answer questions that are frequently raised in the field concerning operation and application of these instruments.

The booklet explains such things as shadow casting, use of the same instrument for electron diffraction, resolution, visual and camera work, specimen preparation, negative and positive replicas, as well as electron and lens theory.

Tool Steels

Crucible Steel Co. of America announces the availability of a newly revised 44-page book entitled, *Tool Steels for the Non-Metallurgist*. Written to present a practical understanding of tool steels without being overly technical, the text is confined to direct, familiar phrases. It is intended to familiarize the nonmetallurgist with the six basic classifications of tool steels, enabling him to better handle the numerous grades within the general classifications.

In addition to a discussion of basic tool steel types, the book also discusses heat-treating technique, and includes tables of pertinent information.

Copies of this booklet can be obtained by writing to the Advertising Department, Crucible Steel Co. of America, P. O. Box 88, Pittsburgh 30, Pa.

Metals and Alloys

Producers of chromium metal and a wide range of master and powdered ferro alloys, the Shieldalloy Corp. has announced a new booklet outlining operations and products made at its Newfield, N. J., plant.

The booklet demonstrates Shieldalloy's use of modern methods and facilities in the processing of welding rod materials, master alloys and other specialized metallurgical and ceramic products.

Copies of the booklet are available by writing to the Shieldalloy Corp., 99 Park Ave., New York 16, N. Y.

Brazing Specification Pamphlet

A 4-page specification describing requirements and procedures for furnace copper brazing in accordance with MIL-B-7883 has been issued by Superweld Corp., North Hollywood, Calif.

The company's process for furnace copper brazing, known as Superwelding, is a thermal process for permanently joining two or more ferrous metal parts under high temperature in an electric furnace. Union is accomplished by intermolecular bonding between the parts using fused filler metal with a melting point below that of the base metal.

The specification covers equipment, material, process and quality control. Copies may be obtained by writing R. E. Jones, President, Superweld Corp., 6840 Vineland Ave., North Hollywood, Calif.

Stainless Tubing and Pipe

Information of interest and value to engineers and designers associated with the use of stainless tubing and pipe is included in a data folder recently published by the Tubular Products Division of The Babcock & Wilcox Co. The 6-page bulletin touches briefly on the attributes of stainless steel and how it can be fabricated. Also included are tables of analyses, mechanical properties, creep strength, physical properties, oxidation resistance of nine of the most popular stainless tubing steels.

Copies of the data folder, known as TB-355, are available free upon request to the division's general sales offices at Beaver Falls, Pa.

Alloys & Fluxes

A new pocket size handy book, 32 pages, 3¼ x 6¼ in., issued by All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y., condenses into ready reference form the considerable data needed by buyers of specialty alloys and fluxes to help them make the desired choices for their particular applications.

Rapidity of metallurgical and chemical developments affecting the welding, brazing, soldering, cutting and tinning of metals, makes this publication of timely interest wherever such supplies have to be specified and bought for use in maintenance, production or construction, according to the manufacturer.

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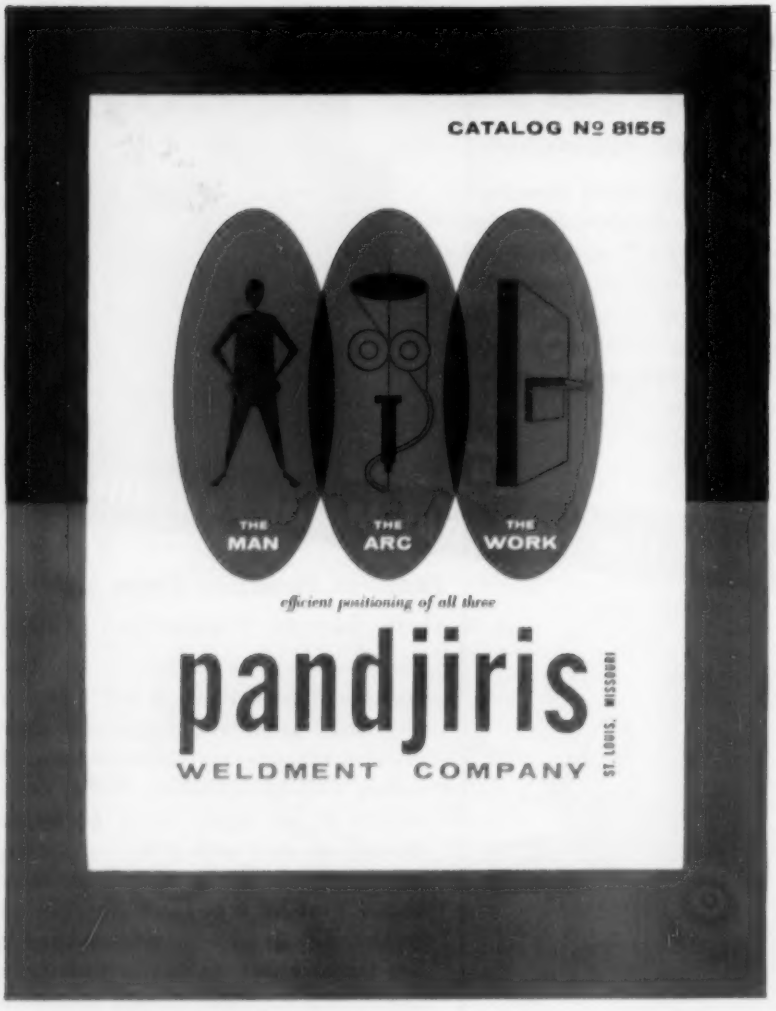

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Hear Latest Welding Developments

Latest trends, developments and uses of welding will be revealed at the National Fall Meeting of the AMERICAN WELDING SOCIETY in Philadelphia, Oct. 17–21, 1955. Over 60 papers covering all phases of welding activity will be presented in the 21 sessions to be held at the Bellevue-Stratford Hotel.

Titled *Buyers Guide to the Complete Line of All-State Alloys and Fluxes*, it supersedes some half a million copies of All-State Buyers Guides of earlier issue, which are made obsolete by the availability in the new issue of data on 15 alloys not previously catalogued.

Copies are available on request and without obligation.

REVIEWS OF NEW BOOKS

Machinist's Handbook

The New American Machinist's Handbook. Edited by Rupert LeGrand, Associate Editor of *American Machinist*. Price $11, 1572 pages. Over 1000 illustrations. Published by McGraw-Hill, 330 West 42nd St., New York 36, N. Y.

The New American Machinist's Handbook is based upon the earlier editions of *American Machinist's Handbook* that were edited for over 45 years by Fred H. Colvin and Frank A. Stanley. Mr. LeGrand has completely reorganized the arrangement and rewritten over 80% of the material to quickly provide full, up-to-date answers to the practical problems in metal working.

A valuable aid to machinists, designers, draftsmen and engineers, this one volume provides useful tables and formulas, plus a convenient-sized encyclopedia of up-to-the-minute information on modern metal-working methods, material and equipment.

All the processes involved in manufacturing a metal product—from raw stock to the final result—are covered in detail. The handbook makes instantly available a wealth of data on machining, metal forming, assembly, metals finishing, inspection, fastening devices, tool engineering and drafting, machine tool standards, and power transmission, plus mathematics and tables.

Welding is one of the many topics covered in this book.

Welding Techniques

Welding Techniques and Uses in the United States. Price $1.00, 300 pages. Format Demy-8vo. Published by The Organization for European Economic Cooperation, Paris. Available through OEEC Missions Publications Office, 2002 P St. N. W., Washington 6, D. C.

Many new applications are nowadays being found for welding, especially in the machinery and building industries. Moreover, new equipment exists which makes possible the mass production of welded parts, or the application of welding processes to metals formerly considered unsuitable for welding. Along with these developments comes a growing need for specialized training among engineers and craftsmen.

The Americans have made great progress in this field in recent years. The task of OEEC Mission No. 143 were to study their organization of research and technical training, and to learn their latest methods, equipment and applications. The Mission's report makes this knowledge available to all "European welders".

The section of the report dealing with technical developments is well illustrated and gives a clear idea of some pieces of equipment designed to increase productivity in processes common to many industries. It includes chapters on testing and inspection, new welding processes, handling devices and structural welding.

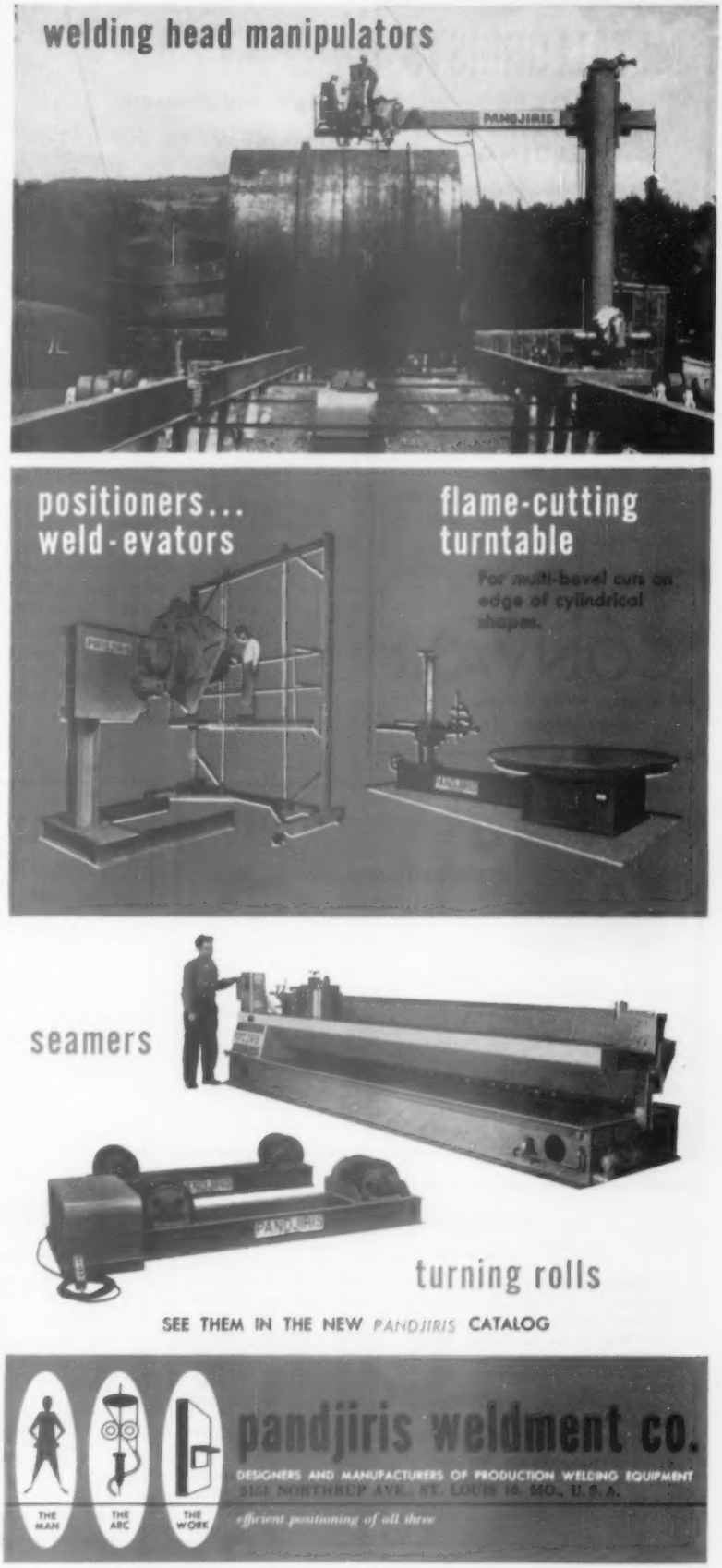
Engineering Metallurgy

Engineering Metallurgy, by L. F. Mondolfo, Illinois Institute of Technology, and Otto Zmeskal, University of Florida. Price, $7.50, 397 pages. Published by McGraw-Hill Co., Inc., 330 W. 42nd St., New York 36, N. Y.

A. This is an up-to-date-book for engineers whose primary interest does not lie in the metallurgical field. While detailed description of methods and operations are given, the emphasis is on the theoretical reasons behind the operations. Thus the basic theory of metallurgy is stressed, not as an end in itself, but as a necessary introduction to the practical applications. Unity of concept is the underlying theme, as opposed to compartmentalization of individual metals' behavior. Because of this approach, the authors make it easy for the engineer to understand how and why metals behave as they do.

Welding is one of the many subjects treated in this book.

B. Based on the authors' extensive experiences in every phase of engineering metallurgy, both industrial and re-



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search, *Engineering Metallurgy* can be of help to anyone interested in this rapidly expanding field.

Weight and Measure

Units of Weight and Measure—Definitions and Tables of Equivalents, by L. V. Judson, National Bureau of Standards Miscellaneous Publication 214, 64 pages, 40 cents. (Order from the Government Printing Office, Washington 25, D. C.)

This publication, superseding Miscellaneous Publication 121 issued in 1936, defines the units of length, mass, area, volume and capacity in use in the United States. It also gives tables of interrelation and tables of equivalents for these units in the metric system and in the U. S. customary system.

In addition, the volume contains sections of the fundamental equivalents, the approved spelling and abbreviation of each of the most common units of weight and measure, and the status of the metric system in the United States. All of the tables and other material have been revised to conform to current definitions, equivalents and usages. Conversion tables are confined to simple units, excluding all compound units such as foot-pounds, pounds per cubic foot and feet per second.

Selfwelding

Selfwelding—A Method for Making Home Projects in Metal, by L. H. Houck. Price $1.00 in U.S.A.; $1.50 elsewhere, postage paid, 128 pages. Published by The Lincoln Electric Co., Cleveland 17, Ohio.

The do-it-yourself fans have been doing just about everything there is to do around a home, but here is something new to try—welding iron furniture tools and other handy home gadgets made of metal. This new book shows what any householder with a home workshop can make and do at home with metal, and how to do it. In addition to detailing some 80 projects revealing a surprisingly wide range of possibilities for metalworking at home, the book also explains a new welding method that the average person can use.

Selfwelding is described as being a new method which requires no special skills and which can be done with equipment within the means and ability of the average householder. By eliminating some of the skills normally required for welding, the Selfweld method is said to make welding almost as easy as turning on a light switch. In addition to welding, with this new method, it is also possible to cut, heat, braze and solder metal.

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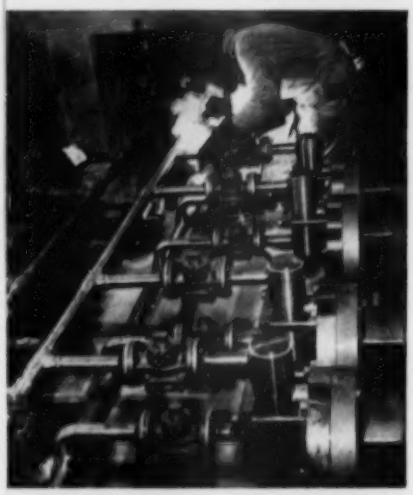

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corner was 5 in., corresponding to 20 in. in actual ship. As shown in the

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WELDING RESEARCH COUNCIL
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SUPPLEMENT TO THE WELDING JOURNAL, OCTOBER, 1955

STRESS STUDIES OF VARIOUS SHAPED WELDED DOUBLER IN HATCH CORNER

Welded ship hatch corner specimens, with doubler reinforcements of various shapes welded thereto, tested under tension to determine the most effective shape of doubler. Trapezoidal and oval shapes found to be the best

BY H. KIHARA, Y. AKITA, N. ANDO AND K. YOSHIMOTO

ABSTRACT. Nine large welded ship hatch corner specimens containing welded doubler reinforcement of various shapes at the hatch corner were tested under tension for determining the most effective shape of doubler. The stress distributions were measured in both elastic and plastic states. The shapes of doubler were circular, eccentric circular, oval, trapezoidal, and rectangular. In addition to the above, a specimen of rectangular insert plate, and a specimen without doubler were tested for comparison.

For all specimens, the maximum stress concentration occurred in the deck plate at the periphery of the hatch corner. The insert plate, eccentric circular, and rectangular reinforcements caused the greatest stress concentration; the circular and oval shapes resulted in intermediate values; and the trapezoidal shape yielded the least stress concentration. Local bending of the deck plate occurred near the periphery of the welded doubler for all reinforcement designs being greater in the eccentric circular shape, and least in the insert plate.

It was concluded that the eccentric circular shape was inferior, and that the trapezoidal and oval shapes were best.

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To be presented at AWS 1955 National Fall Meeting in Philadelphia, Pa., October 17-21, 1955.

Introduction

Many structural failures of welded ships, experienced during and after World War II, have caused various problems on the strength of ships. As many cases of these failures originated from hatch corners, full scale tests of hatch corner specimens have been carried out by DeGarmo at the University of California,[1] and it was concluded that the design, employed in the original Liberty ships was inferior, and A.B.S. design and Kennedy design were excellent. In Japan, studies of the effect of doubler size on the strength of hatch corners was undertaken in 1951 by the Ship Structure Committee established in the Society of Naval Architects of Japan.[2] In 1952, the Panel Committee 2-3 was established in the Japanese Shipbuilding Research Association for research on the hatch corner doublers.[3, 4]

The experiment reported herein, was carried out by the Panel Committee 2-3 to determine the most effective shape of hatch corner doubler. The comparisons of eight shapes, i.e., cir-

was observed at the corner. A little

tude of the maximum stress concentra-

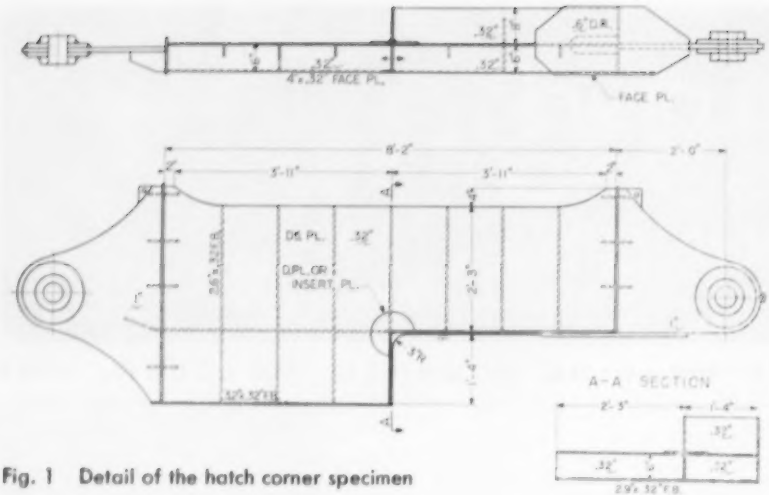


Fig. 1 Detail of the hatch corner specimen

cular shape, oval shape, rectangular shape and trapezoidal shape, etc., were made. The specimens, 1/4 scale of a typical ship, simulated actual ship structure, and were provided with coaming plate, under deck girder, beam and so on. Each specimen was tested under tension by a structural testing machine. The relative superiority of the specimens was compared by measuring the stress distribution at both elastic and partial plastic states by means of resistance wire strain gages.

Previous Experiments

As stated before, the effect of size of welded corner doubling reinforcement was investigated first by the Committee.[2] In this experiment, flat plate specimens having a rectangular opening with rounded corners, reinforced by circular shaped doubler were tested under tension. The specimens consisted of deck plate only, and had no beam or coaming plate. The radius of the hatch corner corresponded to 12 in. in an actual cargo ship of 10,000 ton class. The radius of the circular shaped doubler was changed in four steps. The result showed that the stress concentration at the corner decreases with increase in the doubler radius, however, the stress concentration flattens out at large doubler radius. It was concluded that sufficient effectiveness might be anticipated by a circular welded doubler having a radius ranging from 20 to 25 in. in the case of 10,000 ton class cargo ship.

As a second experiment, the influence of the doubler thickness on the effectiveness of the doubler was examined.[4] In this case, a circular shaped doubler or a rectangular shaped doubler was welded on a wide plate having no opening, and the plate pulled under tension. The stress transmission in the doubler and the mother plate (deck plate) were investigated by stress measurement in the elastic state. The result showed that the tensile stress was transmitted through the doubler equally to that in the mother plate, when the ratio of the length of the doubler to the thickness of the doubler is larger than 20.

The third experiment on the doubler shape reported herein was carried out by the Panel Committee as an extension of the prior investigations.

Specimens

The tested specimens consisted of only one corner of a hatch opening as shown on Fig. 1. Only one corner of the hatch opening was tested since this allowed the largest scale specimen and improved the accuracy of measurement. This method was also adopted in the experiment carried out by DeGarmo.[1] To obtain the same stress field in the one-corner specimen as in an ordinary four-cornered specimen, one side of the specimen was constrained in transverse movement by a supporting structure and wedging as shown on Fig. 2.

Details of the specimens are shown in Fig. 1. The scale of the specimens was about one quarter of 10,000 ton cargo ship. The breadth and length of the specimens were 2 ft 4 in. and 8 ft 3 in., respectively, and the radius of hatch corner was 5 in., corresponding to 20 in. in actual ship. As shown in the figure, these specimens consisted of deck plate, hatch coaming, under deck girder, hatch end beam, and ordinary beam. At the hatch corner, the deck plate and the doubler had the same radius of opening while the coaming plate and under deck girder were welded on both sides of the deck plate slightly outside of the deck opening, as usual in an actual ship.

The shapes of the doublers are listed in Table 1, and are shown in Fig. 4. All doublers were continuously fillet-welded to the deck plate and about four sewing rivets were used as shown in the figure.

Nos. 1 and 2 were basic circular shapes and each was doubler without and with sewing rivets. No. 3 called eccentric circular shape was also a circular shape, but the center of the circle was moved slightly toward the middle of the hatch opening. Nos. 4 and 5 were rather unusual shapes as shown in the figure, and each was called oval shape and trapezoidal shape, respectively, according to their appearance. Rectangular shapes were studied in Nos. 6 and 7, in the latter, however, the doubler was replaced by a thick plate inserted into the deck plate and butt welded to it. No. 8 was also a rectangular shape but the end of the doubler was kept apart from the hatch side coaming, which was called modified rectangular shape. In order to evaluate the effectiveness of the doubler, a specimen No. 9 containing no doubler was employed.

In this experiment, the thickness of the doublers were uniform, and the size of each doubler was varied to obtain equal areas.

Testing Procedure

The specimens were loaded under tension in a structural testing machine having a capacity of 300 ton in the Transportation Technical Research Institute at Tokyo. Stresses at the elastic and partly plastic states were measured by resistance wire strain gages, Type K1 (gage length of 3/4 in.), and Type K22 (gage length of 3/8 in.) which were installed on both sides of each specimen.

Table 1—Specimen Number and Its Shape

Specimen No.	*Shape of doubler*	*Note*
1	Circular shape	Without sewing rivet
2	Circular shape	With sewing rivets
3	Eccentric circular shape	With sewing rivets
4	Oval shape	With sewing rivets
5	Trapezoidal shape	With sewing rivets
6	Rectangular shape	With sewing rivets
7	Rectangular shape	Insert plate
8	Modified rectangular shape	With sewing rivets
9	Without doubler	

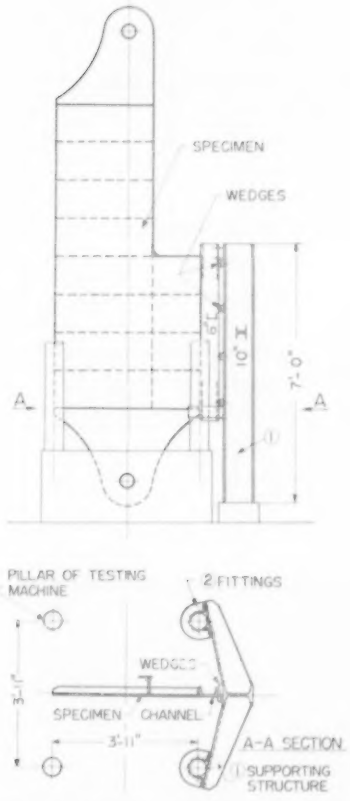


Fig. 2 Specimen pulled in tension and constrained in horizontal movement by a supporting structure

Since the specimens were composed on one corner as described previously, the constraint of the transverse movement at one side of the specimen must be satisfied. To obtain this, a supporting structure was fitted to the columns of the testing machine as shown in Fig. 2, to restrict transverse displacement of the specimen during test. While the transverse constraint actually achieved was not complete, but the conclusion of the test would not be affected since this study was a comparison test. A specimen and the arrangement of the supporting structure are also shown in Fig. 3.

Test Results

The elastic stress distributions on the deck plate are shown in Figs. 5 to 7. The stress values reported are stress factors, the ratio of a given local stress to the mean stress which is taken as the gross load, divided by the gross cross-sectional area in the widest section, including the area of the longitudinals. As shown in the figures, the longitudinal stresses were distributed almost uniformly except at the fore and aft part of the hatch opening, where stresses were slightly lower. As was expected, the large stress concentration was observed at the corner. A little compressive stress was shown along the end coaming.

Figure 8 shows the distribution of tensile stress on the side coaming and the under deck girder in the specimen having a doubler of circular shape. The stresses flow in the under deck girder sufficiently, and also flow into the hatch coaming at some distance from the end of it.

The comparison of stress distribution at the periphery of hatch corner deck plate is shown in Fig. 9. In these figures, R_1, R_2, D_1 and D_2 show the locations of the point of tangency of corner curvature and the end of the doubler, respectively. It can be seen that a small stress concentration occurs at the end of the doubler. The position of the maximum stress concentration exists about 30 degrees inboard from the point of tangency R_1, independently of the shapes of doubler. The magnitude of the maximum stress concentration factors, however, depends on the doubler shape, and range from 3.7 to 4.9, largest in the eccentric shape, intermediate in the circular and oval shapes, and least in the trapezoidal shape. The insert plate, on the other hand, showed a large value of 5.1 and the specimen without doubler showed 6.0.

The longitudinal stresses near the periphery of the doubler are shown in Fig. 10. The "stress on the deck" is the mean value of the upper and lower side at points a, b, c, etc., in the figure. The "stress on the doubler" is the mean value of the upper surface of the doubler and the lower surface of the deck plate at a', b', c', etc., and the "stress by local bending" is the stress differential between the upper and lower side of the deck plate at a, b, c, etc. As shown in the figure, the mean stress on the deck plate at the end of the doubler

Fig. 3 Photograph of specimen and supporting structure

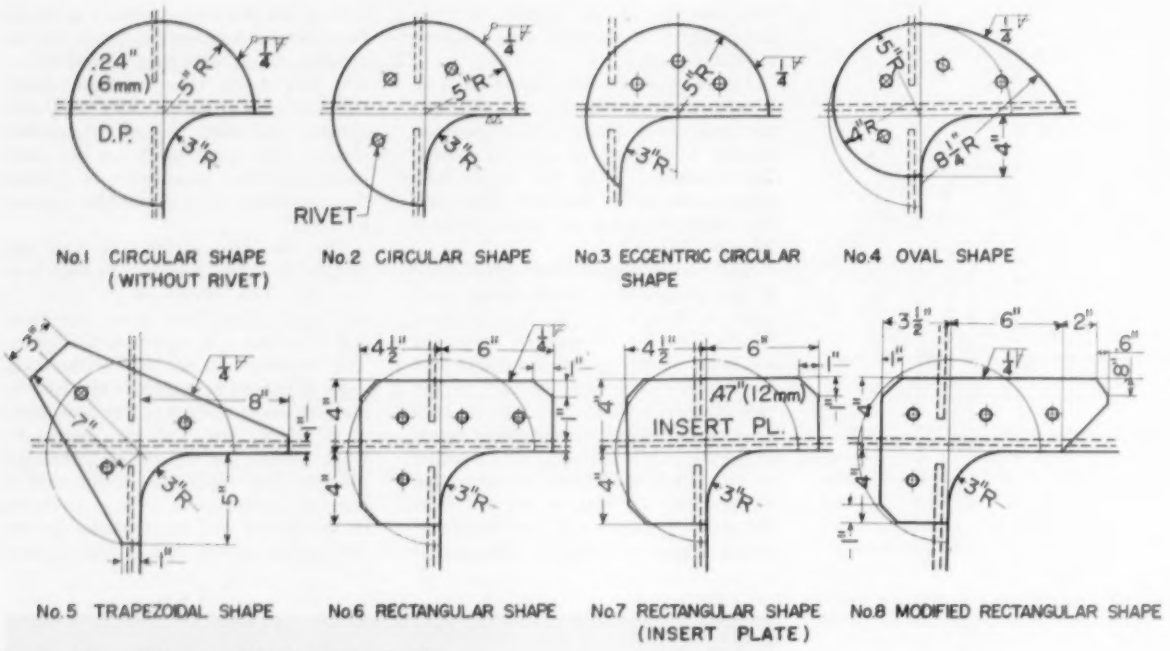


Fig. 4 Several shapes of hatch corner doubler

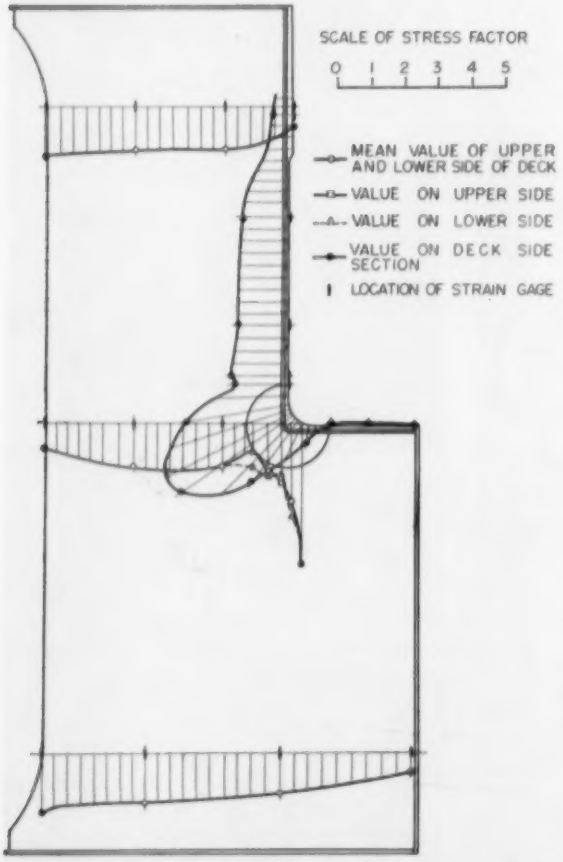
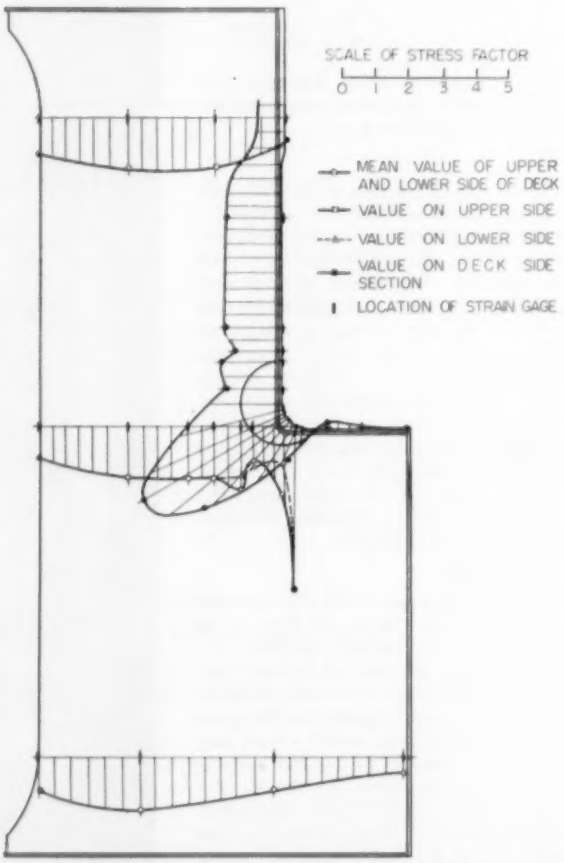

SCALE OF STRESS FACTOR
0 1 2 3 4 5
MEAN VALUE OF UPPER AND LOWER SIDE OF DECK
VALUE ON UPPER SIDE
VALUE ON LOWER SIDE
VALUE ON DECK SIDE SECTION
LOCATION OF STRAIN GAGE

Fig. 5 Stress distribution on the deck of specimen No. 1, circular shape without sewing rivet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VALUE ON LOWER SIDE
VALUE ON DECK SIDE SECTION
LOCATION OF STRAIN GAGE

Fig. 6 Stress distribution on the deck of specimen No. 3, eccentric circular shape

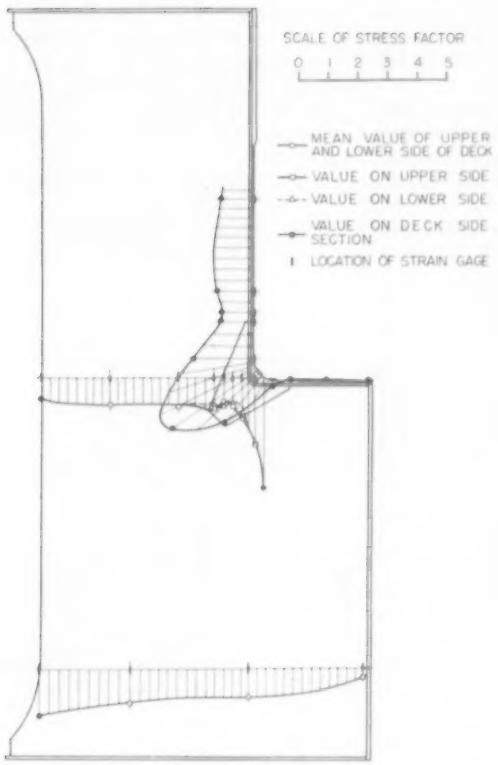
SCALE OF STRESS FACTOR
0 1 2 3 4 5
MEAN VALUE OF UPPER AND LOWER SIDE OF DECK
VALUE ON UPPER SIDE
VALUE ON LOWER SIDE
VALUE ON DECK SIDE SECTION
LOCATION OF STRAIN GAGE

Fig. 7 Stress distribution on the deck of specimen No. 5, trapezoidal shape

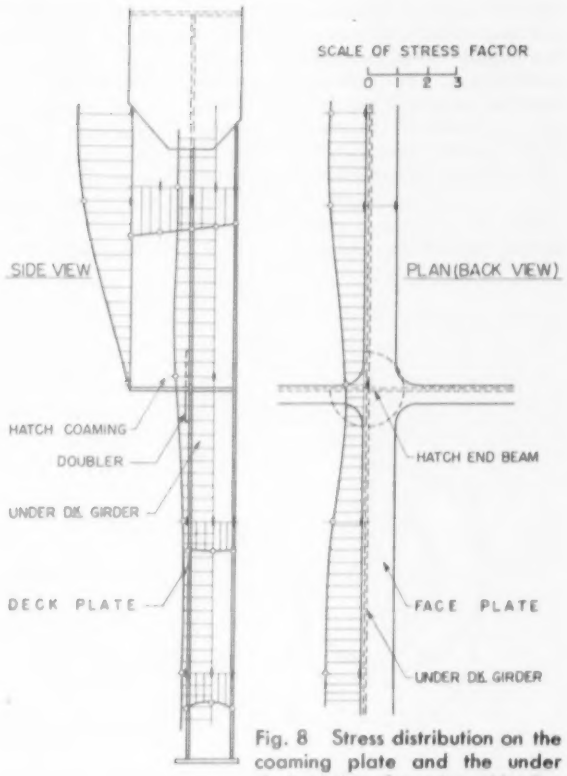

Fig. 8 Stress distribution on the coaming plate and the under deck girder of specimen No. 1

indicates a very large value in the eccentric circular shape, and comparatively small values in the oval shape, trapezoidal shape, and the modified rectangular shape. In the figure, the "stress on the doubler" shows little difference for the various doubler shapes and the stress factor approximates unity. As is expected in the welded doubler, the stress due to the local bending at the end of the doubler occurs, being very large in the eccentric circular shape, rectangular shape, and modified rectangular shape, and being small in the insert plate. Lower part of Fig. 12 shows the comparison of the local bending for the several shapes, in which a full line is the mean value around the doubler periphery.

Figure 11 shows the transverse distribution of the longitudinal stress on both sides of the doubled region. Generally near the periphery of the doubler, (point Q), the stress on the mother plate exceeds that of the doubler. Near the center of the doubler, the

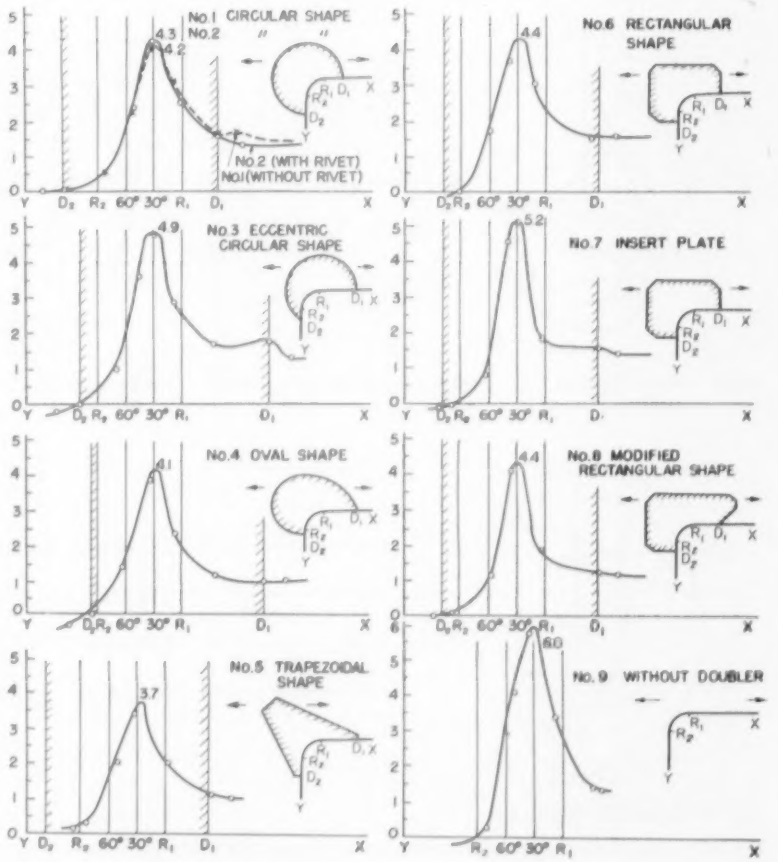

Fig. 9 Stress distribution along the hatch corner of specimens

stress division is approximately equal and near the hatch corner (point P), the doubler stress exceeds that of the mother plate. From the previous stress distribution, the stress divisional ratio, i.e., the ratio of the average doubler stress to the average deck stress is obtained as shown in the middle of Fig. 12 which indicates that the eccentric circular shape effects but little flow of stress in the doubler.

It was noted that the sewing rivets served somewhat to the effectiveness of the doubler, but that its amount was not so great.

The strain distribution was also measured in the partly plastic state. The result showed that the plastic flow occurred at the hatch corner, but the strain concentration factor for the several shapes showed the same tendency as that of the elastic state.

Discussion of the Test Result

Figure 12 summarizes the foregoing experimental results by comparing the several factors investigated. In appraising the effectiveness of the various designs, the desirable considerations include:

(1) Low stress concentration at the hatch corner,

(2) low deck plate stress at the end of the doubler,

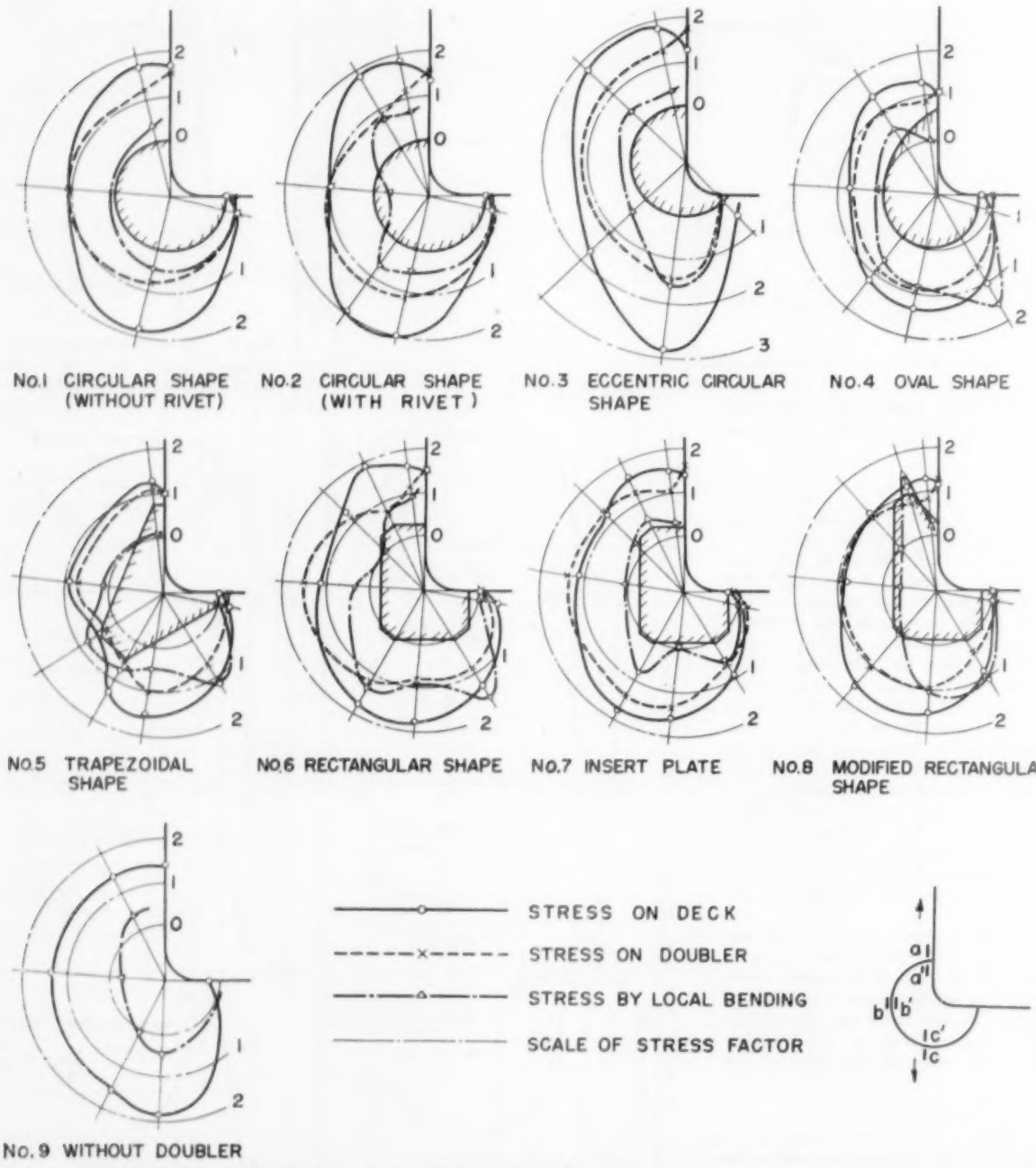

Fig. 10 Longitudinal stress distribution near the periphery of the doubler

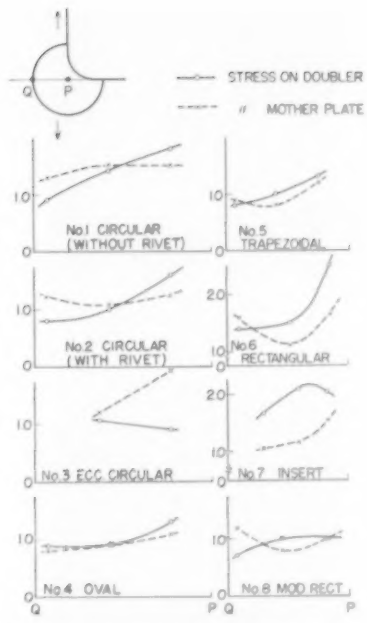

Fig. 11 Transverse distribution of the longitudinal stress on the surface of the doubler and the mother plate

(3) stress divisional rates between doubler and deck plate of unity or greater and

(4) low local bending stress at doubler periphery.

Applying equal weight to the above criteria, the several designs can be rated as follows:

A class: Trapezoidal shape
Oval shape

B class: Modified rectangular shape
Insert plate
Rectangular shape
Circular shape
Circular shape (without sewing rivet)

C class: Eccentric circular shape

Conclusions

Static tensile tests of hatch corner specimens were carried out to determine the most effective shape of welded doubler. The results obtained from the elastic and partly plastic tests are summarized as follows:

1. The maximum stress concentration of the hatch corner occurs about 30° inboard from the point of tangency in the hatch side line, and is independent of doubler shape.

2. The maximum stress concentration factor, i.e., the ratio of the maximum stress to the mean stress in the widest section, depends on the shape of the doubler and ranges from 3.7 in the trapezoidal shape to 5.1 in the insert plate.

3. Stress concentration on the deck plate occurs at the end of the welded doubler, being greatest in the eccentric circular shape.

4. Local bending of the deck plate exists in the vicinity of the welded doubler, and its amount depends upon the doubler shape, being greater in the eccentric circular shape and least in the insert plate.

5. Sewing rivets showed little contribution to the effectiveness of the doubler.

6. Among the several shapes of the doublers studied, the trapezoidal shape and the oval shape were best and the eccentric circular shape was inferior as a welded doubler.

Acknowledgments

The authors desire to thank the Japanese Shipbuilding Research Association for permission to publish this paper. Sincere thanks are also due to Professor M. Yoshiki, S. Makino and other members of the Panel Committee 2-3 in the J.S.R.A. for their expert advice and also to Professor E. P. DeGarmo and Professor J. T. Lapsley in connection with the preparation of the manuscript.

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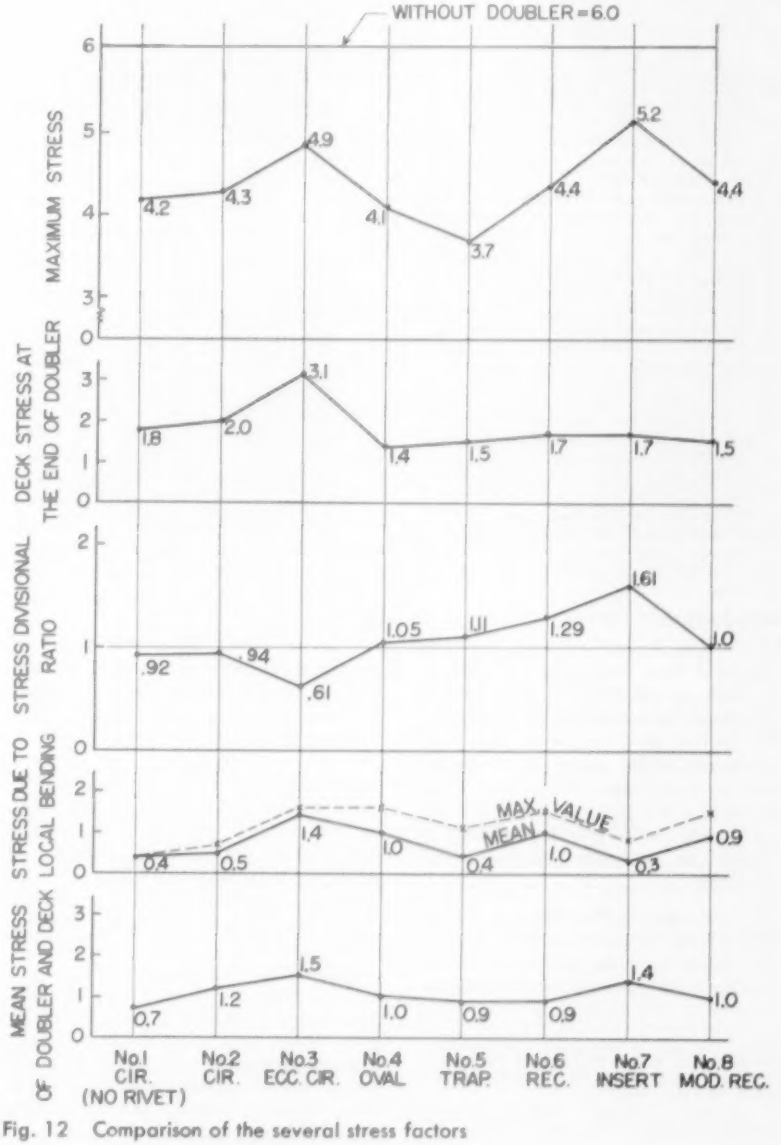

Fig. 12 Comparison of the several stress factors

EFFECT OF PREHEATING ON STRESS-CORROSION CRACKING OF STEEL WELDMENTS

Experimental program shows that preheating is of considerable benefit in reducing stress-corrosion cracking in steel weldments

BY E. PAUL DEGARMO AND I. CORNET

ABSTRACT. Steel weldments 2 ft x 2 ft x 1/2 in., made of three steels having from 0.09 to 0.24% carbon and containing a 2 ft submerged-arc weld, were immersed in an aqueous solution of 60% $Ca(NO_3)_2$ and 3% NH_4NO_3 at 225–235° F in the as-welded, 400° F preheat, and high-temperature stress-relieved conditions. Preheating was found to be of considerable benefit in reducing stress-corrosion cracking. It appeared that the benefits of such preheating were at least as great as have previously been reported to be obtained from controlled low-temperature stress relief, but not as great as from high-temperature stress relieving. The cracks did not start in the welds, but in the heat-affected zone immediately adjacent to the welds. Quantitative data regarding crack growth are shown. These results, together with limited data from supplementary bend tests, lead to a theory that stress-corrosion cracking in weldments results from a combination of stress and some type of discontinuity, and that either low stresses and severe discontinuities or high stresses with small discontinuities may cause cracking.

Introduction

In previous papers[1] evidence has been presented that preheating at 400° F. is about as effective as post-welding stress-relief heat treatment in improving the performance of low-carbon steel weldments under static and repeated loading conditions. In one of these papers it was suggested that it was not yet known whether preheating would be helpful in reducing stress-corrosion cracking.

C. R. McKinsey,[2] in 1953, reported on tests which showed that low-temperature stress relieving provided definite improvement in reducing stress-corrosion cracking, as compared with the as-welded condition. Since these tests did not include post-welding high-temperature stress relieved specimens, no comparison could be obtained of the relative effectiveness of the low-temperature and high-temperature processes. While the investigator did not directly conclude that the improvement brought about from the use of the controlled low-temperature procedure was due to the lowering of the residual stresses, there was no inference that the improvement resulted from any other factor.

One significant factor was noted in McKinsey's results which raised a question as to the role of stress in stress-corrosion cracking. This was the fact that certain cracks did not originate in the weld, but in the area immediately adjacent to the weld. Further, it was possible that all of the cracks originated in this manner. Since it is well established that the residual stresses are higher at the weld centerline than in the plate adjacent to the weld, if stress, per se, were the primary factor causing stress-corrosion cracks, why did the cracks not originate in the welds?

The tests reported here were intended to determine the relative effectiveness of preheating and post-welding, high-temperature stress relieving in reducing stress-corrosion cracking in low-carbon steel weldments and, in addition, to seek an answer to the above question.

Table 1—Composition of the Three Steels Used in Stress-Corrosion Tests

	Chemical composition, %							
Steel	*C*	*Mn*	*Si*	*S*	*P*	*Cu*	*Ni*	*Al*
A	0.24	0.48	0.33	0.049	0.023	0.040	0.032	0.035
B	0.17	0.42	..	0.022	0.010	....	....	....
C	0.09	0.39	0.50	0.033	0.10	0.41	0.40	....

Procedure

Since McKinsey's work provided an excellent basis for comparison, and a satisfactory technique, these tests were carried out with the same type of specimens, the same corrosive medium, and steels which were essentially the same as some he used.

As shown in Fig. 1, each specimen was made of two pieces of 1/2 inch plate, 12 x 24 in., welded together with a 24 in. long submerged-arc weld. Three steels were used, having analyses as shown in Table 1. Six specimens were prepared from each steel. Two were tested in the as-welded condition. Two were given a post-welding stress-relief heat treatment by heating to 1200° F, holding for one hour, and cooling in the furnace. The other two were welded after the plate for 4 in. on each side of the weld was heated to 400° F. This temperature was maintained throughout welding. Before the second side was welded the plates were permitted to cool to below 100° F.

Following welding and any special treatment, the plates were immersed in a bath of 60% Ca $(NO_3)_2$ and 3% NH_4NO_3 with 37% water, and maintained at 225–235° F. All plates were inspected daily for cracking and the point of origin and progress of each crack was recorded.

Results

The results of these tests are shown in

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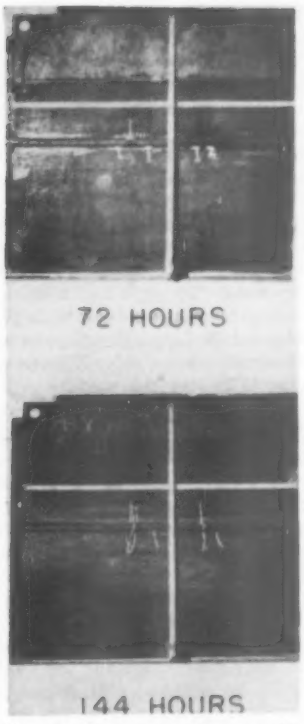

Fig. 1 Stress-corrosion cracks in a welded specimen at different time intervals (specimen 18) showing origin and growth of cracks into weld

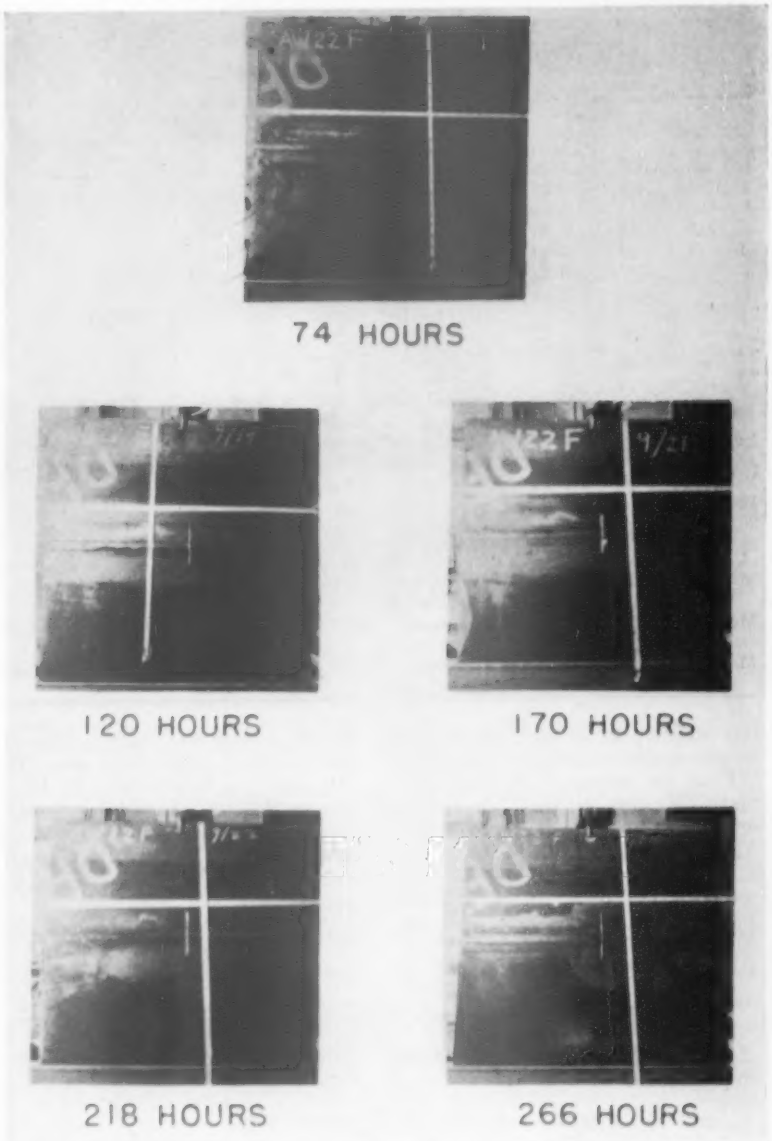

Fig. 2 Growth of stress-corrosion cracks in a welded specimen as a function of time (specimen 22)

tabular form in Table 2. The extent of the cracking reported for the specimens of this test (those numbered) is the sum of the length of the cracks visible on *both* sides of the specimen. In nearly all cases the same crack was plainly visible on both sides of the plate, but in the early stages it might be visible on only one side.

The data below the horizontal double line in Table 2 are from McKinsey's tests and those to the right of the vertical double line are to provide a comparison. *It should be pointed out, however, that since the cracks in McKinsey's and the above tests probably were not measured in the same manner, no significance should be attached to the magnitude of the figures. They should be used only to indicate the presence or absence of cracks.*

It will be noted that none of the specimens made from steel "A" (0.24% C) cracked in 456 hr of immersion.

Of the specimens made from steel "B" (0.17% C) only the as-welded specimens had cracked at the end of 200 hr. McKinsey reported the same results from his low-temperature stress-relieved specimens. When this test was continued, the preheated specimens developed small cracks at 266 hr. It thus appears that 400° F preheating and low-temperature stress relieving are about equally effective in reducing stress-corrosion cracking in this type of steel, and each procedure is not as effective as high-temperature stress relieving.

For steel "C" (0.09% C), at 70½ hr no cracking was obtained on either the high-temperature stress-relieved or the preheated specimens. Since McKinsey reported a small amount of cracking on low-temperature stress-relieved specimens at this same time, and when the tests being reported herein were extended to 144 hr there was still no cracking on the preheated specimens, it appears that 400° F preheat is perhaps slightly the more effective of the two procedures. However, because of the small number of specimens involved, this can not be stated as definite.

Discussion and Supplementary Tests

One of the most apparent results was the effect of increasing carbon content in reducing stress-corrosion cracking. This same effect was found by McKinsey. The corrosion observed was not accompanied by pitting and the surface attack was negligible in penetration.

The fact that the cracks originated in the heat-affected zone of the plate, adjacent to the weld, and then progressed into the weld and outward in the plate, was observed for many of the cracks. This phenomenon is clearly shown in Fig. 1 which shows the condition of Specimen 18 at two times, 72 hr apart. Some of the original cracks can be seen to have crossed the weld and progressed into the other half of the specimen. In every case where a crack

Table 2—Results of Initial Tests

(2 ft x 2 ft x 1/2 in. specimens)

Specimen	*Steel*	*% C*	*Condition*	*Exposure, hr*	*Cracks, in.*	*Exposure, hr*	*Cracks, in.*
1	A	0.24	Heat treated	456	No cracks		
2	A	0.24	Heat treated	456	No cracks		
3	A	0.24	As-welded	456	No cracks		
4	A	0.24	As-welded	456	No cracks		
5	A	0.24	Preheat	456	No cracks		
6	A	0.24	Preheat	456	No cracks		
24	B	0.17	Heat treated	266	0	200	0
25	B	0.17	Heat treated	266	0	200	0
22	B	0.17	As-welded	266	9 13/16	200	9 2/8
23	B	0.17	As-welded	266	10 8/8	200	9 1/8
26	B	0.17	Preheat	266	1 1/2	200	0
27	B	0.17	Preheat	266	5/8	200	0
16	C	0.09	Heat-treated	144	0	70 1/2	0
17	C	0.09	Heat treated	144	0	70 1/2	0
18	C	0.09	As-welded	144	41 1/8	70 1/2	5 1/4
19	C	0.09	As-welded	144	23 7/8	70 1/2	9 13/16
20	C	0.09	Preheat	144	0	70 1/2	0
21	C	0.09	Preheat	144	0	70 1/2	0
McKinsey		0.24	Low-temp. Stress relieve	455	None		
McKinsey		0.16	Low-temp. Stress relieve			200	None
McKinsey		0.08	Low-temp. Stress relieve			70 1/2	2.4

was observed in its early stages, this was the method of initiation and growth.

From the measurements which were made, it appears that the cracks originate and grow in three stages. This is shown photographically in Fig. 2. In Fig. 3 the data for this same specimen are shown in curve form. First, there is an induction period during which no cracks were observed. Next, the cracks appeared and grew rapidly. Finally a stage was reached where the cracks grew at a decreasing rate. This last stage can be accounted for by assuming that the rate of crack propagation was proportional to the stress, and that the stress was inversely proportional to the time the cracks grew at this stage.*

X-rays were taken of the specimens. No cracks were found which had not been observed by visual inspection. Figure 4 shows a portion of one of the X-rays.

The fact that the cracks did not originate in the weld, and that the preheating procedure was as effective as the low-temperature stress-relieving method raises some doubts as to the roll of stress in this type of cracking. The residual stresses in as-welded and preheated specimens were checked by the use of strain gages and, as expected, were found to be of about the same magnitude. There is no question but that the stresses were much higher in the preheated specimens than they would be in low-temperature stress-relieved specimens. Likewise the stresses adjacent to the weld certainly are less than those in the weld. Why, then, were the above results obtained?

In view of the effectiveness of small increases in carbon in reducing the cracking tendency, one might suspect that preheating in some way caused a higher carbon content to exist in the weld zone. A chemical analysis of the weld zone on specimen 20 showed that no such an increase had occurred—in fact, the carbon content in the weld was slightly lower than in the parent plate. Therefore, the answer must lie elsewhere.

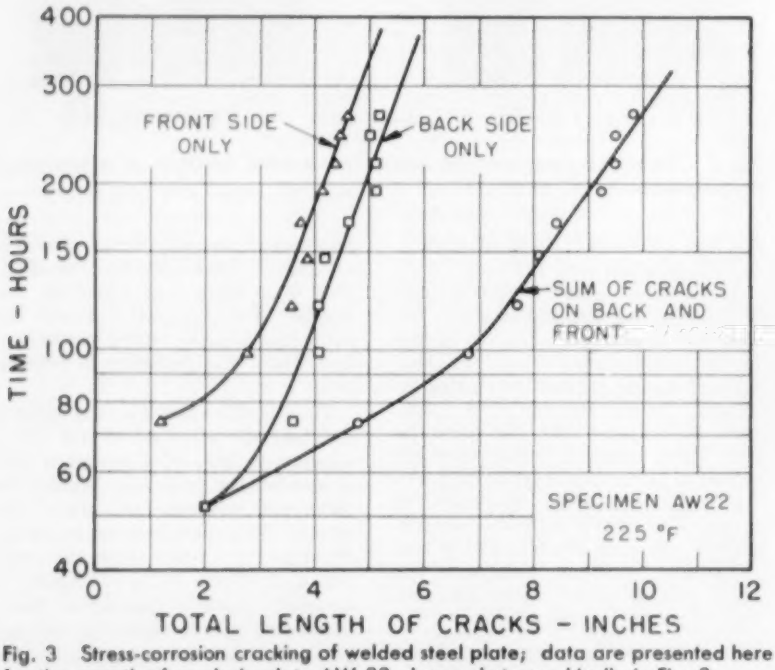

Fig. 3 Stress-corrosion cracking of welded steel plate; data are presented here for the growth of cracks in plate AW 22, shown photographically in Fig. 2

* *Analysis of Final Stage of Crack Growth*

Let L = length of crack
t = time
s = stress
k_1, k_2, K = constants

Assume that the rate of crack propagation is proportional to the stress

$$1. \quad dL/dt = k_1 s$$

Assume also that the stress is inversely proportional to the time the crack grows, at this stage

$$2. \quad s = k_2/t$$

Combining these two simple assumptions

$$dL/dt = k_1 s = k_1 k_2/t = K/t \quad \text{or}$$
$$3. \quad dL/d\ln t = K$$

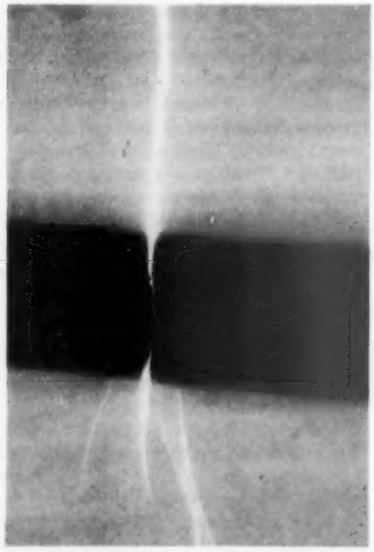

Fig. 4 X-ray of cracks in specimen 18; the three-dimensional nature of crack growth is indicated here

In an attempt to gain further insight into this matter, a series of supplementary tests were conducted. In these tests 2 ft x 2 ft x $^1/_2$ in. specimens of steel "C," the same as were used in the previous tests, were prepared in the as-welded and preheated conditions. These weldments were then sawed into 2 in. wide specimens, transverse to the welds. Each 2-in. specimen was machined on the edges and the welds machined and ground flush with the plate. The finished specimens were placed in a fixture, as shown in Fig. 5, and loaded as a simple beam to a predetermined stress. They were then immersed in the hot brine solution and observed daily.

In order to bring about any corrosion of the 2-in. specimens it was necessary to insulate them, electrically, from the fixture, otherwise the fixtures provided excellent cathodic protection. The effectiveness of cathodic protection has been reported by other investigators.[3]

It should be pointed out that these tests were intended to be only exploratory and are insufficient in number to be conclusive. Therefore, the following results are only indicative.

Table 3 shows the significant results of these tests. It will be noted that no cracks occurred in 312 hr until the nominal stress was raised to 55,000 psi. This is a considerably higher stress level than was measured in the 2 x 2 ft specimens which cracked in less than 70 hr. It is true in the case of the small bend specimens that the breaking stress was transverse to the weld rather than parallel to it as in the larger specimens. However, these results certainly suggest that stress alone is not the answer.

Further insight is gained from the bend specimens which were stressed to 75,000 psi. In grinding the weld reinforcement from these specimens a very slight hair-line groove remained at the edge of the weld. These specimens, both in the as-welded and preheated conditions, cracked within 24 hr. An additional preheated specimen was prepared by grinding a few thousandths of an inch deeper so as to remove the hair-line groove. As noted in Table 3, this specimen had not cracked at the end of 312 hr though also loaded to 75,000 psi.

These results, while not conclusive, suggest that discontinuities, in conjunction with stress, are extremely important in stress-corrosion cracking of weldments. These discontinuities may be in the form of physical notches, microcracks, or sharp changes in microstructure. This theory would account for the fact that the cracking originates in the heat-affected zone, where such discontinuities occur, rather than in the weld. Likewise it would account for the improved performance of preheated weldments since they have a more uniform microstructure, and probably fewer microcracks, than as-welded specimens. While weldments which have been stress relieved by the low-temperature process have lower stresses than preheated specimens, the variation in microstructure and any microcracks are retained. High-temperature stress-relieved weldments have both the variation in microstructure and stresses removed and thus neither condition for producing cracking, under this theory, remains.

Again it must be pointed out that this is theory supported by only a few facts. However, the fact that a preheated specimen can remain free from cracks for over 300 hr when stressed to 75,000 psi and immersed in such a hot corrosive bath, if it is free from surface discontinuities, suggests that further study is justified of this very interesting subject, about which there is much that we do not know.

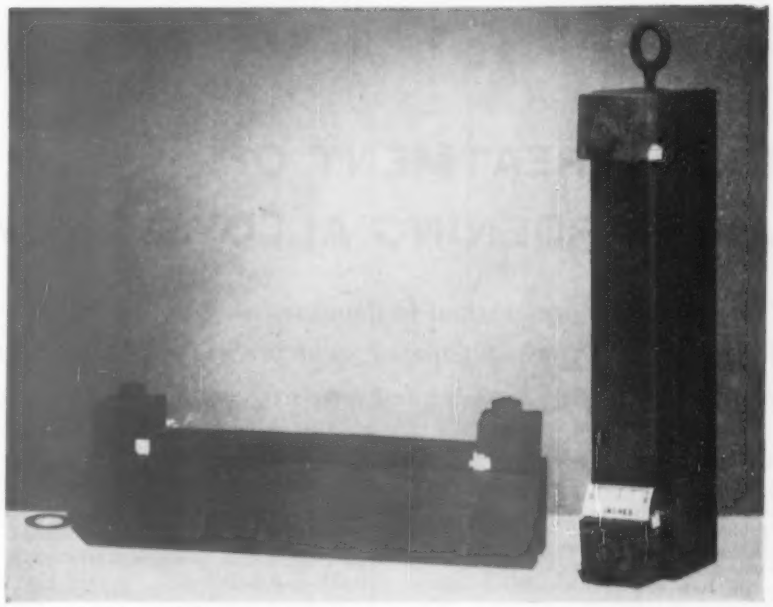

Fig. 5 Bend test fixtures and specimens

Table 3—Results of Bend Test Specimens

(2 x 12 x $^1/_2$ in. welded specimens in 225–235° F aqueous solution of 60% $Ca(NO_3)_2$ and 3% NH_4NO_3)

Nominal Stress, psi	*Hours to Produce Fracture*
30,000	No fracture at 312 hr
45,000	No fracture at 312 hr
55,000	312
65,000	72
75,000	24
75,000*	No fracture at 312 hr

* Surface ground smooth.

Conclusions

From these tests the following conclusions are drawn:

1. Preheating at 400° F reduces stress-corrosion cracking in low-carbon steel weldments.
2. The effectiveness of such preheating is not as great as that of post-welding stress relief at 1200° F.
3. Preheating at 400° F appears to be at least as effective in reducing stress-corrosion cracking as controlled low-temperature stress relieving.
4. Stress-corrosion cracks originate in the heat-affected zone rather than in the weld.
5. Increasing carbon content, at least up to 0.24%, is very effective in reducing stress-corrosion cracking.
6. Stress-corrosion cracking in low-carbon steel weldments is not the result of stress, per se, but of stress in combination with some other factors. Discontinuities of some type appear to be an important one of these factors.

Acknowledgment

The authors wish to express their appreciation to C. R. McKinsey for supplying much useful information, and to C. H. Lockrem and H. H. Bonheyo for their very considerable assistance in preparing the specimens and in conducting the tests.

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HEAT TREATMENT OF AIR HARDENING ALLOYS ON WELDING

Test program undertaken to demonstrate the need for post weld heat treatment and the influence of weld preheating temperature on hardness and microstructure of heat-treated welds of air hardenable alloys

BY J. J. B. RUTHERFORD AND J. F. EWING

ABSTRACT. With the application of welding as a method of fabricating higher carbon and alloy steels, it has become customary to recommend practices of preheating and post-heating, or stress-relieving weldments. Preheating serves mainly to mitigate stresses originating from thermal shock associated with arc welding. A secondary function of preheating is to minimize notch sensitivity or to increase ductility, on the assumption that the base materials might not start from the optimum annealed condition. A high rate of cooling from the welding operation leads to the formation of martensite and results in a highly stressed weldment. The rate of cooling is relative, low-carbon steel may be martensitic on spot welding but this condition is much less likely when large sections or multi-bead practices are involved. If preheating is performed above the Ms (martensite transformation) temperature, then the weld-affected zone will cool rapidly to the preheat temperature but subsequent cooling and martensite formation will be retarded. This is not good practice as it may first appear, because the austenite formed on heating will be retained on cooling, on subsequent stress-relieving and then transform to martensite. On the basis of tests performed during this investigation, it is recommended that the preheating temperature should be significantly below the Ms for the materials involved, and the weld area should be cooled below the Ms before being stress-relieved or annealed.

Introduction

In recent years there has been an accelerating demand for equipment capable of severe service at elevated temperatures and/or pressures. This demand has increased greatly the use of high-strength carbon and alloy steels for structural components where formerly low-carbon steel sufficed.

The Cr-Mo steels make up one family of high-strength alloys which has found wide industrial acceptance for service at elevated temperatures and pressures. The chromium and molybdenum contents of these steels nominally vary between limits of 1 to 9 and ½ to 1%, respectively, while the carbon content for these grades in wrought products is 0.15% maximum.

Certain precautions must be observed in the fabrication of structural components from the Cr-Mo steels as well as other high-strength alloys, which are air hardening to a greater or lesser degree depending upon the specific chemistry. Such precautions are particularly necessary when welding these steels; otherwise excessively hard and highly stressed welds result which possess poor ductility and pronounced susceptibility to impact failure.

In view of these potent air hardening characteristics of high-strength steels, the welding routines established for the non-air hardening grades, i.e., low-carbon steels, have proved inadequate. This necessitates significant modifications in procedure to insure welds with proper engineering properties. One of the most important of such modifications is the need for heat treatment to reduce hardness and improve ductility in both the weld and weld heat-affected zone.

Heat treatment when applied to welding denotes both pre- and post weld thermal treatments. Preheating of the base metal can be of great value in preventing the retention of residual stresses as well as preventing the formation of local hard spots in the heat-affected zone. A correct preheat will also minimize the tendency for distortion about the weld, decrease the rate of heat transfer from the weld, and reduce the magnitude of stresses initially present in the base metal. Otherwise these stresses would supplement transformation stresses originating after welding, thereby increasing the danger of cracking.

Important as the need is for proper preheating of the air hardening grades, this need is frequently exceeded by the necessity for post weld heat treatment to transform the usually hard and brittle as-welded joint to one possessing suitable engineering properties. The intention of any post weld heat treatment is to modify the microstructure produced in and adjacent to the weld so as to reduce notch sensitivity from sudden changes in hardness and structure. It also effects a general improvement in the structural, mechanical and corrosion-resisting properties of the welded members

In any consideration of post weld heat treatments it should be remembered that extreme heterogeneity of structure exists in and adjacent to the fusion area of the weld. This heterogeneity is created because metal temperatures in the weld area range from either ambient or preheat temperature to fusion which results in considerable variation of grain size, degree of carbide solution, and microconstituents. The type of heat treatment applied upon completion of the welding cycle, consequently, must of necessity be governed by the metallurgical changes it is intended to effect.

Post weld heat treatments can be classified into two broad categories: those involving a thermal treatment above the transformation temperature, i.e., full annealing, and those in which a subcritical anneal or stress relief is used. Complete refinement of the structure in the weld and heat-affected zone is realized in full annealing by heating into the austenite region. Such heat treatments, however, are frequently costly, lengthy and difficult to apply to air hardening alloys, particularly in the field, since they necessitate a controlled slow cool to insure transformation of the austenite into the desired microconstituents. The subcritical anneal subsequent to welding is gaining in popularity since these treatments do not require controlled cooling; consequently they are easier to apply, and will impart suitable properties to the weld when properly done.

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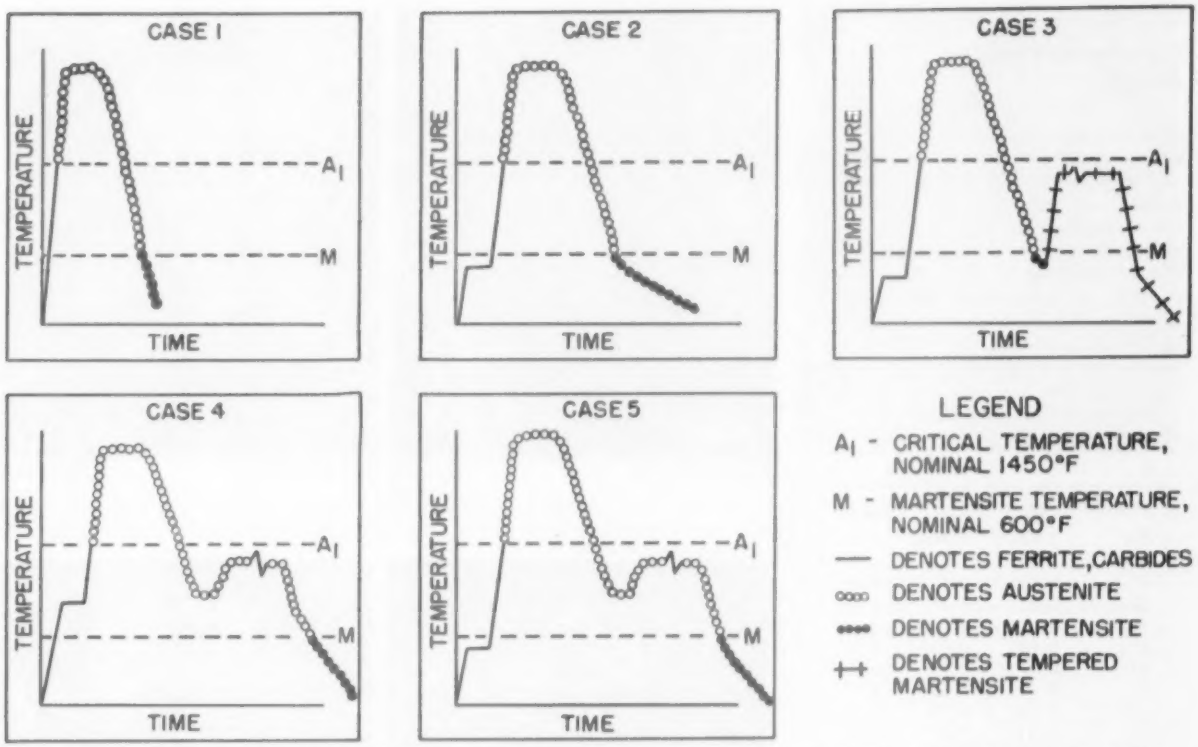
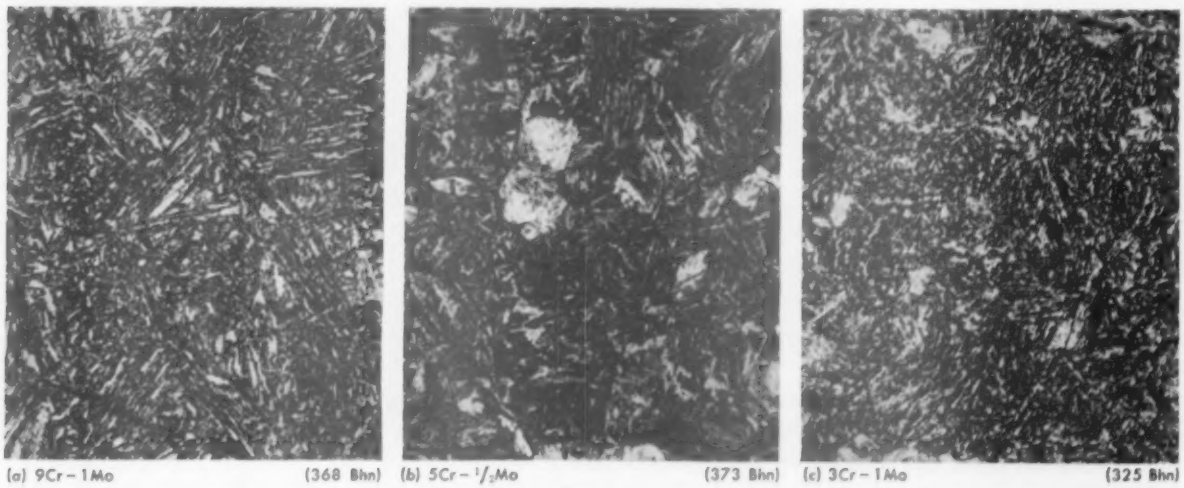


Fig. 1 Schematic representation of relationship between preheating temperatures, subcritical annealing and final microstructure for air hardening alloy welds

Structural alterations during the subcritical anneal of the air hardening steels are limited largely to softening through stress relief and tempering of the hard martensite and/or bainite formed in those areas of the weld cooled from above the critical temperature.

The purpose of the present investigation was to emphasize the need for post weld heat treatment of air hardenable alloys such as the Cr-Mo steels, and to demonstrate the influence of preheating temperatures upon the final hardness and microstructure after supposedly proper post weld subcritical annealing. Emphasis has been placed upon experiments designed to illustrate the need for using proper preheating temperatures. These must be sufficiently high to properly function and at the same time sufficiently low to permit transformation to the desired properties during subsequent subcritical annealing, even in the more strongly air hardening alloys. Fitch in a recent publication[1] recognized the need for proper preheating by emphasizing the necessity for cooling a ferritic weldment until it is magnetic prior to reheating for stress relief.

The primary interests governing the selection of the thermal treatments studied were the changes occurring in those areas of the heat-affected zone which were heated above the transformation temperature during welding. It is these areas together with the weld deposit which largely account for the hard and brittle as-welded properties of



(a) 9Cr – 1Mo (368 Bhn) (b) 5Cr – ½Mo (373 Bhn) (c) 3Cr – 1Mo (325 Bhn)

Fig. 2 Microstructure and hardness of 9Cr – 1Mo, 5Cr – ½Mo, and 3Cr – 1Mo after heating to 2000°F for 10 min and air cooling to room temperature. Etch: HCl and picral. × 250

the air hardening steels.

Experimental Procedure

Materials

The 9 Cr-1 Mo alloy was selected for principal consideration in this investigation since this alloy is representative of the high-strength alloys possessing potent air hardening characteristics. Supplementing the work on this material, however, were similar studies on the 5Cr – ½Mo and 3Cr – 1Mo alloys in order to demonstrate the influence of total alloy content on the behavior of the air hardening alloys during various thermal treatments. The following tabulation presents the complete chemistry of the three alloys used for these studies.

Element	*9Cr–1Mo*, %	*5Cr–½Mo*, %	*3Cr–1Mo*, %
C	0.11	0.11	0.11
Mn	0.42	0.47	0.44
S	0.011	0.015	0.017
P	0.023	0.015	0.024
Si	0.37	0.37	0.29
Cr	8.70	4.85	2.93
Mo	0.94	0.53	0.89
Ni	0.34	0.22	0.33
Cu	0.11	0.12	0.16

All test material was obtained from commercially processed basic electric furnace stock normally used for tubular products.

Heat Treatment

Emphasis in these studies was primarily concerned with the need for post weld heat treatment, and demonstrating the potent influence of preheating temperature upon resultant changes in hardness and microstructure during subsequent subcritical heat treatment.

In these studies numerous thermal conditions representative of those which could be achieved during welding were simulated by heating specimens (2-in. lengths of ¾-in. bar stock) to peak temperatures above the transformation temperature, and subjecting them to various thermal treatments using several furnaces.

The need for post weld heat treatment was emphasized by cooling specimens from 2000° or 2400 to 1300° F and below, holding for sufficient times and air cooling.

The studies of preheat influences were based upon the concept that the primary influence of preheating upon post weld subcritical annealing is to govern the lowest temperature reached after welding and before stress relieving since in effect the base metal acts as a cold sink. This important influence was demonstrated by cooling specimens

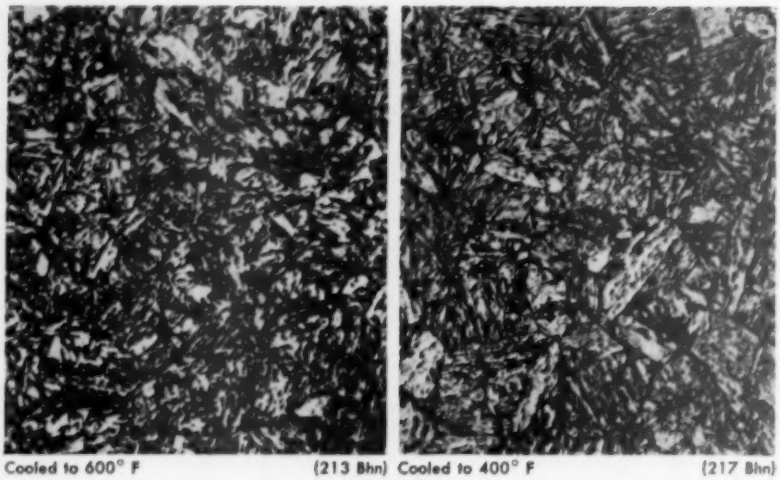


Fig. 3 Microstructure and hardness of 9Cr – 1Mo, 5Cr – ½Mo and 3Cr – 1Mo after holding 10 min at 2000° F, cooling to either 600° or 400° F, 10 min and reheating to 1300° F, 1½ hr and air cooling. Etch: HCl and picral. × 250

(a) 9Cr – 1Mo (215 Bhn) (b) 5Cr – ½Mo (218 Bhn) (c) 3Cr – 1Mo (214 Bhn)

Fig. 4 Microstructure and hardness of 9Cr – 1Mo, 5Cr – ½Mo, 3Cr – 1Mo held 10 min at 2000° F, air cooled to room temperature, reheated to 1300° F, 1½ hr and air cooled. Etch: HCl and picral. × 250

from a peak temperature of 2000° F to different temperatures representative of possible preheating temperatures, and then immediately reheated for subcritical annealing.

A peak temperature of 2000° F was considered representative for those areas in the heat-affected zone heated sufficiently high to place all significant carbides into solution to assure high hardenability. In view of the strong influence of grain size on hardenability however, some work was done using a peak temperature of 2400° F in order to obtain data on those areas of the heat-affected zone heated close to the fusion point.

A final subcritical anneal of 1300° F for 1½ hr was used for all three alloys since service experience has demonstrated the adequacy of this temperature and time as a proper post weld heat treatment. All test specimens were air cooled following this 1300° F heat treatment.

The various heat treatments studied are presented in Table 1 and may be divided into three principal groups.

1. Heating to 2000° F, holding 10 min and either air cooling to room temperature or cooling to 1300° F, and holding for 1½ or 4 hr, or cooling to 1000, 600 or 400° F, and holding 30 min. All specimens were air cooled after the 1300, 1000, 600 and 400° F treatments.

2. Heating to 2400° F, cooling directly to 1300° F, holding for either 1½ or 4 hr and air cooling.

3. Heating to 2000° F, holding 10 min, cooling directly to either 1000, 800, 600 or 400° F for 10 min, or to room temperature followed by immediate heating to 1300° F for 1½ hr and air cooling.

Groups 1 and 2 emphasize the need for proper post weld heat treatment while Group 3 demonstrates the potent influence of preheating on subsequent heat-treated properties of the weld.

Testing

Hardness measurements and metallographic examinations were the criteria used to demonstrate the influence of possible thermal treatments on the properties of air hardenable alloys exemplified in these studies by the 9Cr – 1Mo, 5Cr – ½Mo, and 3Cr – 1Mo steels.

Results and Discussion

The results of this investigation may be conveniently discussed in terms of Fig. 1 in which five different welding cases have been schematically presented. These cases illustrate practices for air hardenable alloys which might occur in the shop, and which apply primarily to arc welding.

Case 1.—This case in Fig. 1 denotes the arc-welding practices generally used

Table 1—Influence of Heat Treatment on the Brinell Hardness of the 9Cr–1Mo, 5Cr–½Mo and 3Cr–1Mo Alloys

Heat Treatment	*Brinell Hardness*		
	9Cr–1Mo	*5Cr–½Mo*	*3Cr–1Mo*
Heat to 2000° F, hold 10 min, air cool to room temperature	368	373	325
Heat to 2000° F, hold 10 min, cool directly to 1300° F, hold 1½ hr, air cool	368	183	226
Heat to 2000° F, hold 10 min, cool directly to 1300° F, hold 4 hr, air cool	252	145	158
Heat to 2400° F, hold 10 min, cool directly to 1300° F, hold 1½ hr, air cool	363	363	302
Heat to 2400° F, hold 10 min, cool directly to 1300° F, hold 4 hr, air cool	319	329	239
Heat to 2000° F, hold 10 min, cool directly to 1000° F, hold 30 min, air cool	373	375	329
Heat to 2000° F, hold 10 min, cool directly to 600° F, hold 30 min, air cool	372	363	325
Heat to 2000° F, hold 10 min, cool directly to 400° F, hold 30 min, air cool	368	363	319
Heat to 2000° F, hold 10 min, cool directly to 1000° F, hold 10 min, reheat to 1300° F, hold 1½ hr, air cool	331	195	224
Heat to 2000° F, hold 10 min, cool directly to 800° F, hold 10 min, reheat to 1300° F, hold 1½ hr, air cool	329	210	207
Heat to 2000° F, hold 10 min, cool directly to 600° F, hold 10 min, reheat to 1300° F, hold 1½ hr, air cool	213	195	207
Heat to 2000° F, hold 10 min, cool directly to 400° F, hold 10 min, reheat to 1300° F, hold 1½ hr, air cool	217	212	205
Heat to 2000° F, hold 10 min, air cool to room temperature, reheat to 1300° F, hold 1½ hr, air cool	215	212	214

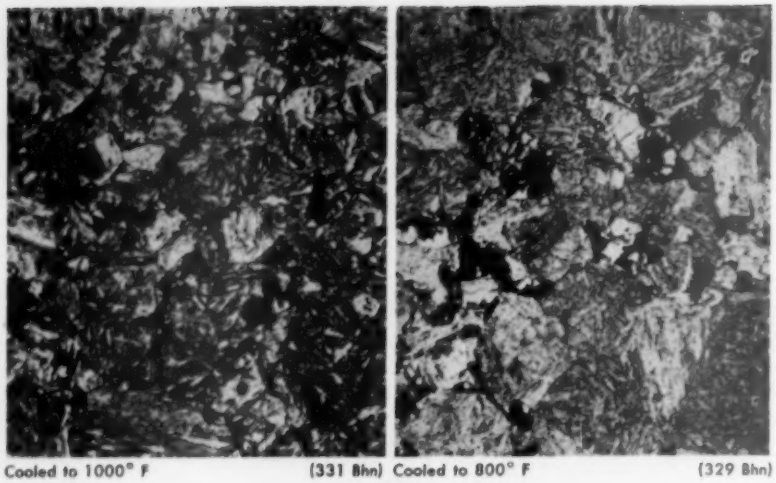
for low-carbon steels as well as other alloys possessing low hardenability, and consequently requiring no special preheat or post weld heat treatment. Trouble will result however, when these simple routines are applied to the welding of air hardenable steels, analogous to the 9Cr – 1Mo, 5Cr – ½ Mo, and 3Cr – 1Mo grades. As shown in Table 1 and Fig. 2, the hardness of all three of these alloys is well over 300 Bhn, while the microstructures are essentially martensite when air cooled to room temperature from above the transformation temperature. Such hardness and microstructure necessitate heat treatment in order to obtain desirable engineering properties in the weld.

Case 2.—In Fig. 1, Case 2 represents the welding routine considered as Case 1 to which a preheat has been added. This preheat in addition to minimizing distortion and cooling stresses results in increased time at the peak welding temperatures together with a slower rate of cooling, particularly below the preheat temperature.

The influence of this welding routine using various preheat temperatures on the final hardness and microstructure of 9Cr – 1mo, 5Cr – ½Mo, and 3Cr – 1Mo welds was studied by cooling directly from 2000° F to various temperatures, i.e. 1000, 600 and 400° F, holding for 30 min. and air cooling. It is recognized that a 30 min hold at these lower temperatures is unduly long in terms of actual welding practice. Nevertheless it was used in order to exaggerate any effect of preheating alone on final as-welded hardness and microstructure.

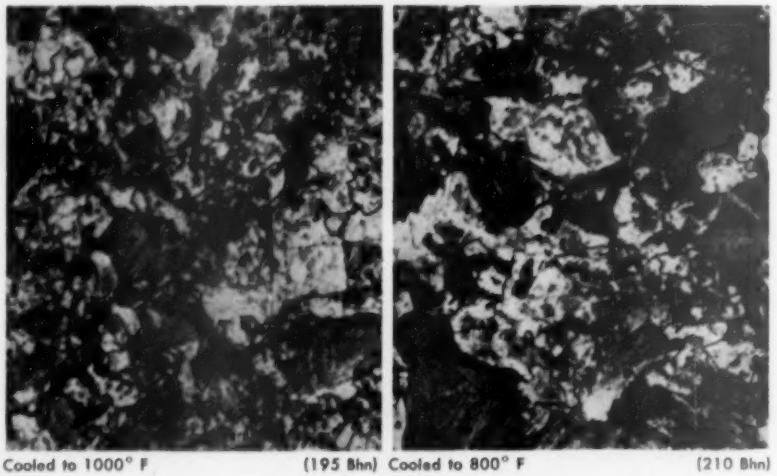
As shown in Table 1, the hardnesses are equivalent to those obtained by cooling directly to room temperature. Metallographic studies also indicated the structures were essentially untempered martensite and/or bainite as shown for the air cooled specimens in Fig. 2. Consequently the use of preheating alone will accomplish little in the way of obtaining the desired properties in the air hardenable welds exemplified by these three Cr-Mo steels.

Case 3.—This case in Fig. 1 represents a welding routine for air hardenable alloys in which both the preheat and post weld subcritical anneal are properly applied to effect desired weld properties. The hardness and microstructure attained by such welding routines for 9Cr – 1Mo, 5Cr – ½Mo, and 3Cr – 1Mo are presented in Table 1 and Fig. 3. These data, obtained by cooling the specimens from 2000° F to 600 and 400° F, holding 10 min and then reheating to 1300° F for 1½ hr followed by air cooling, show that the hardness for all three steels approximates 205–215 Bhn, while the microstructure consists of tempered



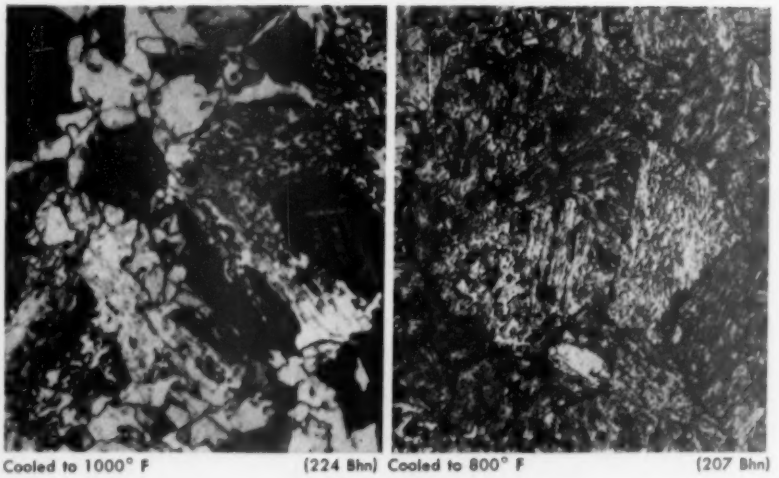
Cooled to 1000° F (331 Bhn) Cooled to 800° F (329 Bhn)

(a) 9Cr – 1Mo



Cooled to 1000° F (195 Bhn) Cooled to 800° F (210 Bhn)

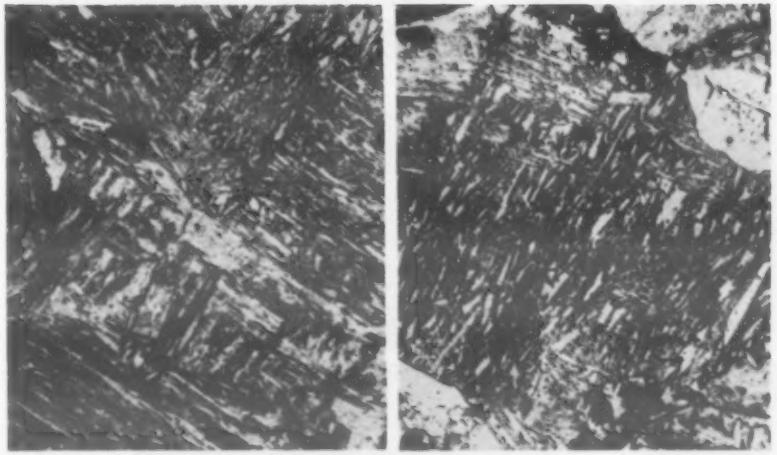
(b) 5Cr – ½Mo



Cooled to 1000° F (224 Bhn) Cooled to 800° F (207 Bhn)

(c) 3Cr – 1Mo

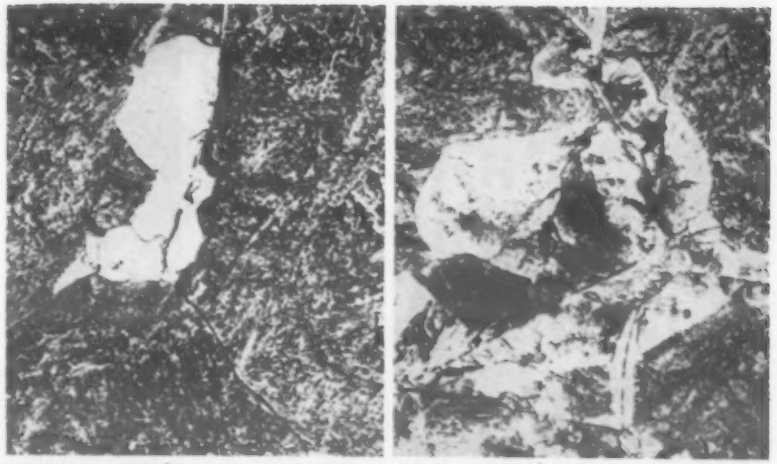
Fig. 5 Microstructure and hardness of 9Cr – 1Mo, 5Cr – ½Mo and 3Cr – 1Mo after holding 10 min at 2000° F, cooling either to 1000° or 800° F, 10 min, reheating to 1300° F, 1½ hr and air cooling. Etch: HCl and picral. × 250



Held 1½ hr at 1300° F (363 Bhn) Held 4 hr at 1300° F (319 Bhn)
(a) Cooled from 2400° F

Held 1½ hr at 1300° F (368 Bhn) Held 4 hr at 1300° F (252 Bhn)
(b) Cooled from 2000° F

Fig. 6 Microstructure and hardness of 9Cr – 1Mo held 10 min at 2400° or 2000° F, cooled to 1300° F, held either 1½ or 4 hr and air cooled. Etch: HCl and picral. × 250



Held 1½ hr at 1300° F (363 Bhn) Held 4 hr at 1300° F (329 Bhn)
(a) Cooled from 2400° F

Held 1½ hr at 1300° F (183 Bhn) Held 4 hr at 1300° F (145 Bhn)
(b) Cooled from 2000° F

Fig. 7 Microstructure and hardness of 5Cr – $\frac{1}{2}$Mo held 10 min at 2400° or 2000° F, cooled to 1300° F, held either 1½ or 4 hr and air cooled. Etch: HCl and picral. × 250

martensite and/or tempered bainite. Such combinations of hardness and microstructure should produce excellent weld properties.

Figure 4 illustrates the structures obtained by permitting the alloys to air cool to room temperature prior to reheating to 1300° F for subcritical annealing. The hardnesses and microstructures are essentially equivalent to those obtained by cooling only to 600 or 400° F and then reheating to 1300° F.

Case 4.—The welding routine represented by Case 4 in Fig. 1 employs both preheating and subcritical annealing. It is very similar to Case 3, except that the preheat temperature is excessive. To demonstrate the influence of high preheat temperatures, specimens of the three test alloys were cooled from 2000° F to 1000 and 800° F, held 10 min and reheated to 1300° F for 1½ hr and air cooled.

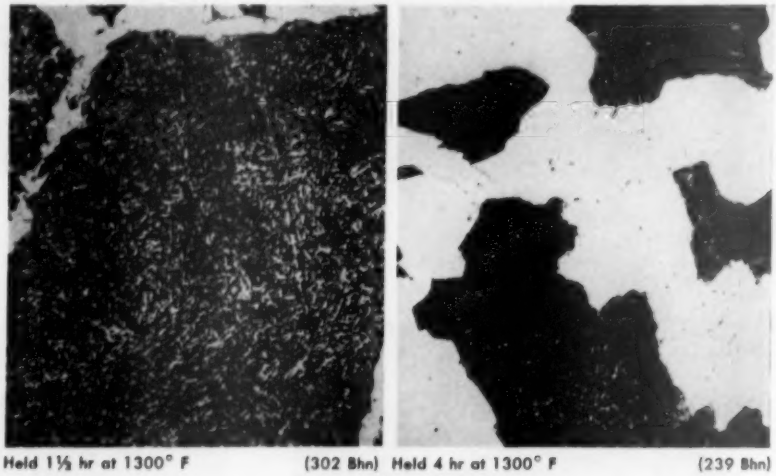
As shown in Table 1, the hardness of the highly air hardenable alloys, as denoted by the 9Cr – 1Mo steel, after such treatment is excessive (329–331 Bhn). The microstructure consisting of untempered martensite and shown in Fig. *5a*, explains the reason for the high hardness. The high hardenability of these alloys dictates that the weld must be cooled below the martensite transformation temperature range prior to any subcritical anneal. This means cooling to at least 600° F for 9Cr – 1Mo. Unless this is done the subcritical anneal will be of little value since austenite will still persist and will transform to martensite during subsequent air cooling. This will result in essentially the same properties as obtained by simply air cooling from above the critical temperature.

The influences of cooling from 2000° F to 1000 or 800 ° F on lesser air hardenable alloys, such as 5Cr – ½Mo and 3Cr – 1Mo, prior to reheating for subcritical annealing were somewhat different than on the 9Cr – 1Mo steel. These differences were related primarily to the lower hardenability of the former two steels. Substantial softening, see Table 1, resulted in both alloys from these thermal treatments. Even so preheat temperatures of 1000 and 800° F are not to be recommended for the 5Cr – ½Mo steel since significant quantities of untempered martensite persist in the final structure as shown in Fig. *5b*. These quantities of martensite will impart undesired characteristics to the weld properties. In the case of the 3Cr – 1Mo steel a preheating temperature of 1000° F also results in the presence of considerable martensite in the final structure (Fig. *5c*) and should not be used. However, an 800° F preheat may be acceptable for 3Cr – 1Mo since as shown in Fig. *5c* a rapid bainite reaction apparently occurs at 800° F. which transforms the austenite prior to reheating for subcritical annealing. Thus the presence of untempered martensite and/or bainite is prevented in the final structure.

An interesting sidelight to these particular thermal cycling studies on the 9Cr – 1Mo alloy was the observation that the start of transformation at 1300° F can be hastened if the alloy is cooled first from 2000° F to 1000 or 800° F for 10 min and then reheated to 1300° F for 1½ hr. Compare Figs. *5a* and *6b*. Previous work on the 9Cr – 1Mo[2] steel established that no transformation occurs within 10 min at either 1000 or 800° F.

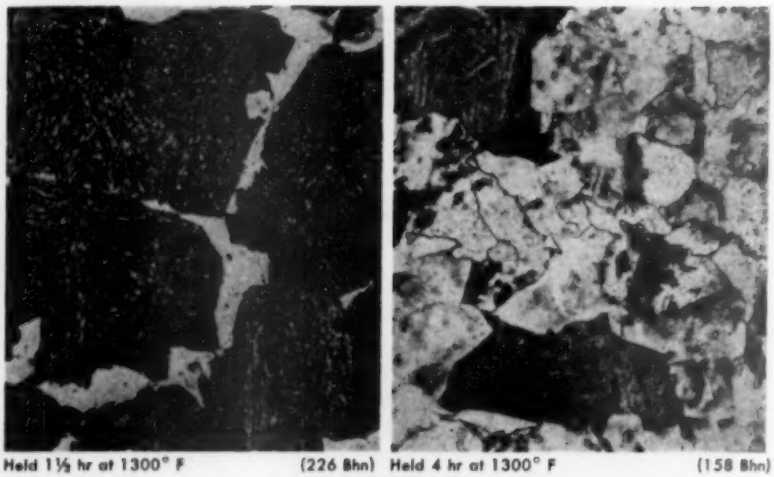
Case 5.—The drawing in Fig. 1 designated as Case 5 represents a welding routine for air hardenable alloys in which a proper preheat and final subcritical anneal are used, but that either the weld is given an immediate subcritical anneal after welding or insufficient time is allowed for cooling after welding and before heat treatment. The effects of these routines on hardness and microstructure of air hardenable steels were demonstrated by cooling directly from 2000° or 2400 to 1300° F and holding for both 1½ and 4 hr followed by air cooling. The results of these tests presented in Table 1 and Figs. 6, 7 and 8 are very similar to Case 4. Again the austenite is not permitted to transform prior to subcritcal annealing so that the final structure, even after a four hour heat treatment at 1300° F, contains substantial quantities of untempered martensite or bainite. Consequently, the weld properties are no better than those obtained for an unheat treated weld of the air hardenable alloys.

A comparison of the hardnesses and structures of specimens cooled from 2400° and 2000 and held at 1300° F for the same periods of time is particularly important. Compare routines



Held 1½ hr at 1300° F (302 Bhn) Held 4 hr at 1300° F (239 Bhn)

(a) Cooled from 2400° F



Held 1½ hr at 1300° F (226 Bhn) Held 4 hr at 1300° F (158 Bhn)

(b) Cooled from 2000° F

Fig. 8 Microstructure and hardness of 3Cr – 1Mo held 10 min at 2400° or 2000° F, cooled to 1300° F, held either 1½ or 4 hr and air cooled. Etch: HCl and picral. × 250

2 and 4, and 3 and 5 in Table 1 and Parts *a* and *b* in Figs. 6, 7 and 8. The majority of the thermal cycles studied in this investigation involved a peak temperature of 2000° F since this temperature is sufficiently high to place all significant carbides in solution and thereby obtain high hardenability. However, the above comparison of data for the 2000° and 2400° F specimens clearly demonstrate that the difficulties in the heat-affected zone resulting from premature subcritical annealing of the weld progressively increase as the peak temperature approaches the melting point. This increase in difficulty can be attributed primarily to higher hardenability and is the result of increasing the grain size as the peak temperatures are raised. Moreover, it is certain that any of the difficulties resulting from improper welding routines as studied in the other four cases in this investigation will be accentuated similarly as the peak temperatures attained during welding in the heat-affected zone approach the fusion point.

Summary and Conclusions

The purpose of this investigation was to demonstrate both the need for post weld heat treatment and the potent influence of weld preheating temperatures on the hardness and microstructure of heat-treated welds of air hardenable alloys typified by the 9Cr – 1Mo, 5Cr – $^1/_2$Mo and 3Cr – 1Mo steels. The following conclusions resulted from these studies.

1. Simple air cooling of air hardenable welds from above the transformation temperature to room temperature will result in excessively hard and brittle welds, highly stressed and possessing low-impact resistance.

2. Cooling air hardenable welds from peak welding temperatures directly to 1300° F for subcritical annealing is inefficient for obtaining desirable changes in weld properties. These welds must be cooled below the temperatures required for complete transformation to martensite and/or bainite before reheating for subcritical annealing.

3. The use of excessive weld preheating temperatures for air hardenable alloys may easily result in the presence of important quantities of hard untempered martensite in welds supposedly given a proper subcritical anneal.

4. Increasing the peak temperatures in the weld heat-affected zone accentuates the difficulties resulting from improper preheating and post weld subcritical annealing.

5. Data were presented for the 9Cr – 1Mo alloy indicating that the start of transformation at 1300° F can be speeded up by first sub-cooling to 1000 or 800° F and then reheating to 1300° F for transformation.

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THE EFFECT OF SPECIMEN SIZE, NOTCHES AND GRAIN SIZE ON THE FATIGUE STRENGTH OF STEEL

BY C. MASSONNET

(Abstract of "Le Dimensionnement des Pièces de Machines soumises à la Fatigue," published in *Revue Universelle des Mines*, 9 T11, 203–222 (June 1955). The author is Professor at the University of Liège.) Abstracted by Dr. G. E. Claussen.

Although welded specimens were not studied in this investigation, size, notches and grain size frequently are problems in welded design. An aluminum-killed 0.35% carbon steel made in an electric furnace was used for all specimens. In all tests the stress was completely reversed. Size effect was studied in axial tension-compression, alternating bending, rotating bending and reversed torsion. Specimen diameters ranged from 0.08 to 2.20 in. Shape of specimen was studied in alternating bending using rectangular specimens from 0.16 x 1.26 to 1.26 x 0.16 in. and square specimens from 0.20 to 0.79 in. Notched specimens had Neuber hyperbolic notches of seven degrees of severity (stress concentration factors in axial tension from 1.84 to 7.06) and were tested under axial tension-compression and alternating torsion. The effect of grain size was studied on smooth and notched specimens in tension-compression. Three grain sizes (ASTM 2, 4 and 7, tensile strengths not stated) were produced by heat treatment. Finally, the effect of mechanical and electrolytic polishing was studied. Besides these tests a series was included to determine the effect of stress gradient using flat specimens with holes from 0.02 to 1.26 in. diam (stress gradient divided by nominal stress varied from 27.85 to 0.39). These specimens were tested in tension-compression.

The machines used for the tension-compression tests were the Baldwin-Sonntag SF-1-U, the 10-ton Amsler Vibrophore (electromagnetic) and the 25-ton Amsler pulsator. In alternating bending and alternating torsion the Baldwin-Sonntag machine was used. For rotating bending the Matra machine and two Schenck machines were used.

The results showed, first of all, that electrolytic polishing produced more reproducible Wohler curves than mechanical polishing. The electrolytic polish removed 0.004 to 0.008 in. of metal and was applied to the smooth specimens and all but the most severely notched specimens.

The effect of size was negligible in tension-compression and alternating bending, regardless of shape of specimen. In rotating bending the fatigue strength was 28% higher for the 0.08-in. specimens than for the 1.26-in. specimens (40,700 compared to 31,900 psi)

(Continued on page 517-s)

INITIAL CHARACTERISTICS OF CHROMIUM-NICKEL STEEL WELD METALS

Controlled temperature unnotched tensile test used to study high-temperature brittleness of weld metals which may, under adverse conditions, lead to microfissuring, cracking or even rupturing

BY J. HEUSCHKEL

ABSTRACT. Studies were made of the temperature sensitivity of iron base chromium-nickel steel metal-arc weld metals under tensile stress. Some compositions and structures exhibit a low order of ductility in the as-deposited condition over a temperature range which is centered at 1800° F. From direct observations it is known that cracking has been experienced for all the welds wherein the ductility at 1800° F was low. These include the structures which are fully austenitic at room temperature. The 1800° F ductility is inversely proportional to the weld metal strength at that temperature. More specifically, in the as-deposited condition, it is shown to be inversely proportional to the product of the matrix strengthening and the grain boundary weakening components of the composition. The matrix is strengthened at 1800° F by nickel and niobium (= columbium), the niobium being 19 times as effective as nickel. It is weakened by the additions of chromium. The grain boundaries are weakened by the presence of oxides, nitrides, carbides and silicates, even when the sulfur and phosphorus contents are maintained as low as 0.015%. The stronger matrixes require lower impurity contents for the maintenance of a specific ductility level. The stronger matrix compositions, being more strain sensitive, are susceptible to cracking in the presence of sharp notches under stressed conditions at the higher temperatures. Solution heat treatment is effective in improving ductility of the niobium-bearing welds at both normal and high temperatures but to achieve that advantage it is necessary to heat the as-deposited weld metal through the brittle temperature range. Massive, rigid weldments made of compositions which are brittle in the as-deposited condition may crack under such treatment unless special precautions are taken.

Introduction

Direct contact with shop and service experiences has demonstrated the hot crack susceptibility of some of the industrially used chromium-nickel-steel metal-arc deposited weld metals under some conditions of stress. These experiences extend, in varying degrees, to the nonmagnetic face-centered-cubic compositions which are austenitic at room temperatures and also to those which contain different amounts of magnetic body-centered-cubic ferrite and/or other phases in an austenitic matrix. The sound weld metals in question, which are included within the commercial AISI 300 series, are ductile at room temperatures, that is, at that temperature they have substantial capacity to flow and to contract in cross-sectional area when subject to high tensile stresses. Unfortunately, the high-temperature tensile properties of these weld metals have not been published and the many cracking studies reported in the absence of such data have led to conflicting conclusions.

Short-time tensile tests up to 2200° F as described herein, when correlated with observed cracking experiences, demonstrate that the low ductility often found even in low sulfur and phosphorus content welds is closely related to the cracking problem. The low ductility region was often found to be centered around 1800° F. It is concluded that the low ductility results from having a matrix with a high capacity to transmit stress to the grain or subgrain boundaries which are weakened at the elevated temperatures by the presence of oxides, nitrides, carbides and silicates. This conclusion is compatible with the observations of Chang and Grant for other alloy systems under creep conditions.[1]

Localized weakening of the grain or particle boundaries results in an inadequate capacity to flow under high stresses. It was found that the yield stress is essentially equal to the ultimate stress above 1500° F.

Cracks in production may form at low magnitudes of strain at one or more of four different time periods, each of which requires the presence of a minimum temperature-stress-strain circumstance. These time periods are:

(*a*) during first solidification of the weld metal behind the arc crater,

(*b*) following a successful first solidification but occurring in once sound metal a short distance behind, beneath or in front of a subsequent advancing arc crater,

(*c*) after successful completion of an entire weldment but during the heating or holding

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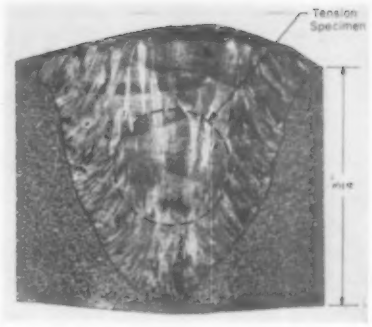


Fig. 1 Typical test weld showing specimen location

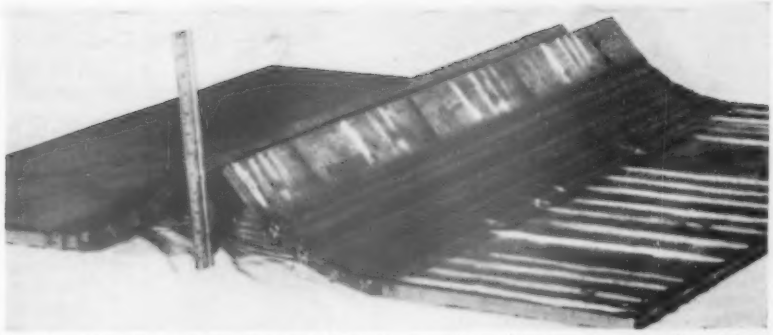


Fig. 2 Warping tendencies in Cr-Ni steel welds. (Restraint is translated into internal stresses and strains)

period involved in a subsequent heat treatment; and/or

(*d*) after successful completion of an entire weldment but during service under stress at temperatures at least as low as 1050° F within time periods as short as one year, with or without the usage of postwelding heat treatments.

Undetected or unrepaired cracking or microfissuring which occurs in any one of the earlier stages probably accelerates the occurrence of more extensive cracking in any later stage in the listed time sequences, although under certain circumstances cracking or microfissuring may occur in any one of the three later stages without the necessity for the existence of even microcracks in any of the prior stages.

Only in recent years have these metals been used in massive rigid sections at elevated temperatures under stress. The compositions and techniques were not originally designed for such service. Therefore, in spite of the fact that such welds have been in general usage for at least 25 years, a brief but searching reexamination of their short-time temperature sensitivity to tensile strain was considered to be necessary.

The cracking sometimes experienced only under the fourth condition enumerated (i.e., after extended service at elevated temperatures) is partially related to factors involving metallurgical instability under the specific temperature-stress conditions involved. Even for wrought metals there is a deterioration in both elevated temperature strength and ductility with time under stress.[2] Metals which have a pronounced dip in the temperature ductility curve probably become weak and brittle after a period of time under stresses and temperatures which are lower than desired.

The questions of crack sensitivity and low ductility at high temperatures extend also to the immediately adjacent welding heat-affected zone of the base metal. However, except for one illustration, this paper is limited to a discussion of the properties of weld metals alone, considered as a free body, since a treatment of the subject of initial sensitivity of the as-deposited weld metal to temperature is, in itself, an involved matter. The findings of most general interest to the welding industry, including summary formulas and curves for specifically describing the composition, strength and ductility relations at the critical temperature of 1800° F, are described. It is hoped that the publication of the present data and the analysis thereof will stimulate others toward more fruitful expenditures of effort in achieving improvements in the many weld metals which may presently contain similar or related correctable deficiencies.

Table 1—Weld Metals Tested

Discussion group	*AISI type*	*1800° F elongation (%)*	*Fig. ref.*	*Percent measured ferrite*	*Check analysis (%)*															*Code mark*
					Cr	*Ni*	*Nb*	*Mn*	*Si*	*C*	*N*	*O*	*Mo*	*Ti*	*W*	*Cu*	*Ta*	*P*	*S*	
I	310 Si	5.6	3	0.0	24.5	19.3	0.03	1.52	2.02	0.09	0.039	0.028	0.10	0.04	...	0.10	0.0	0.014	0.014	O
	310	12.7	4	0.1	25.9	19.8	0.03	1.40	0.41	0.11	0.035	0.051	0.13	0.04	...	0.20	0.0	0.018	0.020	L
	330	7.8	5	0.4	17.1	33.0	0.03	1.64	0.52	0.16	0.019	0.028	0.06	0.04	...	0.08	0.0	0.009	0.011	N
II	308	18.6	6	9.3	20.2	10.0	0.00	1.45	0.44	0.05	0.048	0.05	...	0.06	...	0.12	0.0	0.020	0.022	F
	309	31.3	7	9.8	24.7	13.7	0.03	1.60	0.49	0.08	0.048	0.042	0.11	0.05	...	0.13	0.0	0.019	0.014	P
III	312	46.6	8	27.0	27.3	9.4	0.03	1.40	0.47	0.10	0.044	0.049	0.06	0.03	...	0.12	0.0	0.019	0.011	R
IV	321	38.6	9	6.5	17.3	9.6	0.01	1.49	0.74	0.07	0.013	0.013	0.13	0.34	...	0.11	0.0	0.006	0.023	V
	316	26.6	10	7.5	19.6	12.4	0.03	1.26	0.31	0.06	0.029	0.054	1.99	0.02	...	0.13	0.0	0.014	0.018	M
V	349	17.4	11	19.0	20.9	9.2	0.94	1.58	0.62	0.11	0.036	0.05	0.46	0.03	1.40	0.12	...	0.005	0.017	X
	347	5.7	12	10.0	19.9	9.9	0.81	1.56	0.69	0.05	0.046	0.05	...	0.06	...	0.14	0.035	0.025	0.013	A
		8.2	...	4.5	19.3	10.7	0.66	1.63	0.63	0.06	0.064	0.05	...	0.07	...	0.07	0.020	0.023	0.018	5
		8.4	13	15.7	21.7	9.2	0.81	1.61	0.63	0.06	0.084	0.04	0.07	...	...	0.11	...	0.005	0.020	S
		12.1	14	0.2	19.1	11.6	0.87	1.62	0.59	0.05	0.085	0.01	0.07	...	...	0.11	...	0.005	0.015	U
		19.7	15	5.7	19.5	11.2	0.81	1.56	0.73	0.04	0.041	0.03	...	0.07	...	...	0.043	0.014	0.008	H
		14.5	16	6.5	19.8	11.1	0.25	1.66	0.71	0.04	0.055	0.02	...	0.05	...	...	0.014	0.012	0.009	I
					Avg =	1.53	0.57	0.08	0.046	0.040	...	...	...	...	...	0.12	...	0.014	0.016	

Table 2—Welding Conditions

Code mark	*Discussin group*	*Build-up*	*No. of passes*	*Wire type*	*Arc shielding source*	*Plate type*	*Arc amp*	*Arc volts*
O	I	Beads	7	310*	Covering	304	185	25
L		Beads	7	310	Covering	304	185	25
N		Beads	7	330	Covering	304	185	25
F	II	Beads	8	308	Covering	304	185	25
P		Beads	7	309	Covering	304	185	25
R	III	Beads	7	312	Covering	304	185	25
V	IV	Layers	4	321	Argon	304	315	28
M		Beads	7	316	Covering	304	185	25
X	V	Beads	7	347	Covering	304	185	25
A		Beads	8	347	Covering	347	185	25
5		Beads	8	347	Covering	347	185	25
8		Beads	7	347	Covering	347	185	25
U		Beads	7	347	Covering	347	185	25
H		Layers	4	347	Argon	304	265	31
I		Layers	4	308	Argon	347	280	31

* With silicon specially added from coating.

All welds were made with direct current, reverse polarity (plate cathode.) All covered electrodes were $^{5}/_{16}$ in. diam and all automatic bare argon shielded wires were 0.06 in. diam. All interpass bead or layer temperatures at time of striking of arc were 200° F. Lime type coatings used throughout.

Test Method

The conventional weldability tests in common usage were considered to be inadequate for the problem at hand.[4] Cracking can be made to occur with varying degrees of difficulty in most of the metals under study but even for the most sensitive ones such forced cracking is limited to restricted regions and the specific conditions of occurrence are undefinable by existing standards. Tests which fail to reveal the temperature-stress-strain-time conditions of occurrence of cracking are of little scientific value. Most conventional weldability tests fall within that category.

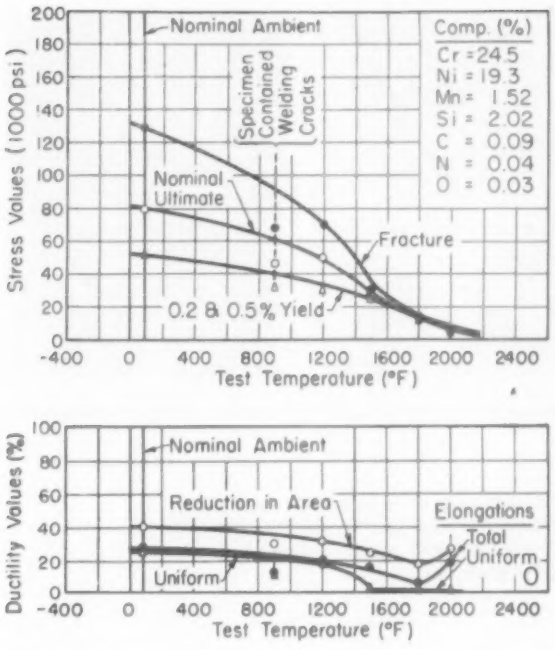
It was postulated that if, instead of welding under restrained conditions in an attempt to induce cracking as is conventionally done, one would make welds under relatively unrestrained tensile conditions, and even under compression if necessary to avoid cracking, and then rupture individual free sublengths of only the solidified metal at controlled temperatures and tension strain rates under continuously measured loads, an understanding of the conditions necessary for occurrence of fissuring and cracking with existing weld metals would readily be secured. Existing laboratory devices for making constant strain rate unnotched tensile tests under controlled temperatures meet these conditions. For the present it will be necessary to assume that this condition provides the same results as are secured in initial weld cool-downs but in the final summary it will be shown that the technique described successfully classifies existing weld metals in the same order as cracking difficulties are observed in the commercially encountered experiences. Thus a powerful tool for a better understanding of the conditions necessary for the formation *and the prevention* of cracks is provided.

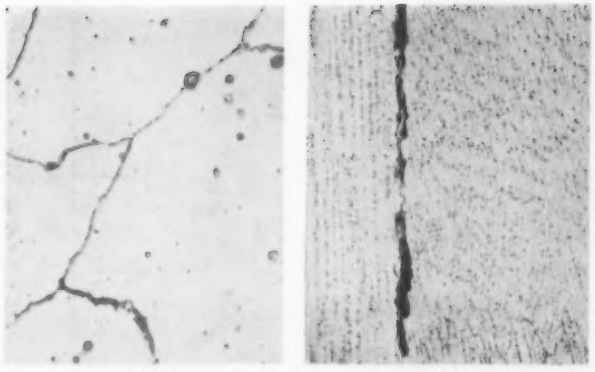
Table 3

A. [illegible] VALUES

OBSERVATION	TEST TEMPERATURE (°F)														
	-300	-100	+80	450	800	1000	1100	1200	1300	1400	1500	1600	1800	2000	2200
Test Mark	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	304-10
Proportional Limit, psi	64,000	63,000	59,800	61,750	37,600	34,200	33,300	28,250	25,000	21,700	19,200	13,500	8,700	—	2,950
0.2% Yield Stress, psi	75,600	70,200	67,400	66,500	41,400	37,500	36,000	30,950	27,650	24,150	21,500	15,250	10,650	—	3,550
0.5% Yield Stress, psi	80,600	75,600	69,000	67,600	42,600	38,500	37,000	32,100	28,800	25,050	22,100	15,900	10,900	6,140	3,590
Ultimate Stress, psi	167,000	130,000	80,800	63,200	59,000	53,400	48,300	40,050	34,450	28,200	23,200	16,000	10,950	6,680	3,610
Fracture Stress, psi	686,200	298,900	184,800	138,250	116,300	99,250	95,800	74,000	56,800	52,400	30,480	19,200	10,140	—	6,000
Elongation, Uniform, %	37.33	43.71	33.38	31.10	23.35	23.86	19.36	17.76	15.00	7.66	3.50	0.93	0.66	1.0	0.61
Elongation, Total, %	44.33	51.63	43.14	38.85	33.00	35.27	30.90	34.36	43.50	47.90	47.98	28.25	18.59	33.0	28.31
Reduction in Area, %	53.20	59.90	62.30	63.70	60.90	60.20	59.90	56.80	55.10	58.50	44.60	36.70	24.50	42.8	63.70
Fracture Appearance	Cup Silky	Cup Silky	Cup Silky	1/2 Cup Silky	Irreg.Cup	Irreg.Cup	Irreg.Cup	45° Sl.Crevice	45° Crevice	45° Crevice	Sl.Woody	Irreg.Woody	Irreg.Woody	Irreg.Woody	Irreg.Wood
Side Fissures	No	No	No	No	No	No	No	No	Small	Small	Yes	Yes	Yes	Yes	Yes
Hardness, Sutton, DPH	221	209	215	210	219	223	218	206	193	198	176	183	183	—	166
Hardness, Shank*, DPH	430	404	314	287	281	289	268	244	246	219	200	188	174	—	167
Hardness, Increase, DPH	209	195	99	77	62	63	50	38	53	27	24	5	11	—	2
Measured Ferrite, Shank*	37	31	9.0	9.3	8.1	6.9	7.0	6.5	5.5	5.2	5.0	4.3	4.2	—	2.2
0.2% Yield/Ultimate Stress	0.45	0.59	0.71	0.72	0.70	0.70	0.75	0.77	0.80	0.83	0.93	0.98	0.97	—	0.98
Elong. x Ult. Stress x 10^{-6}	7.46	6.32	3.65	1.95	1.35	1.72	1.47	1.38	1.46	1.34	1.11	0.65	0.30	0.22	0.10
B. RELATIVE VALUES															
0.2% Yield	1.52	1.32	1.00	.81	.70	.63	.63	.54	.48	.42	.37	.27	.19	.09	.06
Neutral Ultimate	2.66	1.49	1.00	.78	.73	.66	.60	.50	.43	.35	.29	.20	.14	.08	.04
Total Elongation	0.98	1.16	1.00	.68	.73	.71	.68	.76	.92	1.06	1.06	.63	.41	.72	.62
Reduction in Area	.85	.96	1.00	1.02	.98	.96	.96	.91	.88	.93	.71	.59	.39	.67	1.02

*After rupture.





×2000 ×100

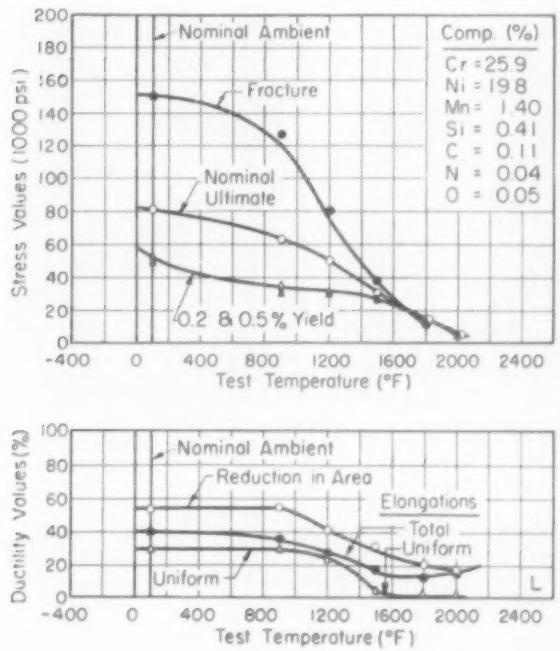
As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

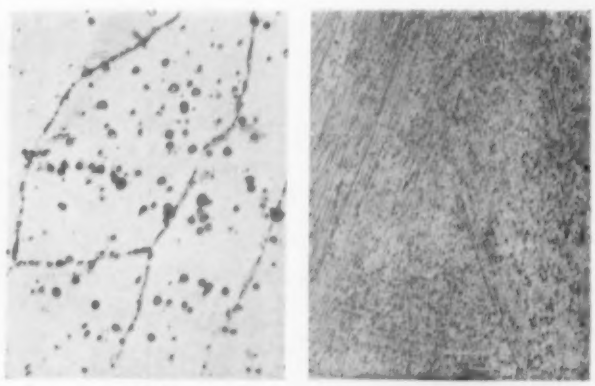
Fig. 3 Influence of temperature upon short-time tension properties of austenitic type 310-Si (25 Cr + 20 Ni + 2 Si) weld metal as-deposited with covered electrodes

Results from a series of 15 single-U grooved welds in $^5/_8$ or $^3/_4$-in.-thick plates will be described, Fig. 1 and Table 1. The test plates were unrestrained during welding and each weld caused a deformation of about ten degrees in the plate, Fig. 2. In practice, particularly in massive structures, such tendencies toward deformation would be converted into internal stresses and strains. There is, therefore, no necessary relation between cracking experienced in these laboratory welds and those made in the field. It will be shown that there is a definite relation between high-temperature brittleness in sound welds and their tendency to crack under restrained conditions.

The individual welds made with each test electrode were either 19 or 38 in. long, depending upon the completeness of temperature effect coverage desired. Conventional deposition procedures were used, Table 2. Except for three instances, welds U, S and O, all electrodes were from commercially available stock. The three special electrodes were experimentally extruded to provide the ranges of silicon and room temperature ferrite contents desired for test purposes.

The test welds were machined into 2.25-in. long by 0.357-in. diam button head tensile specimens, the center longitudinal axis of the specimen being coincident with the central axis of the weld, Fig. 1. Except as

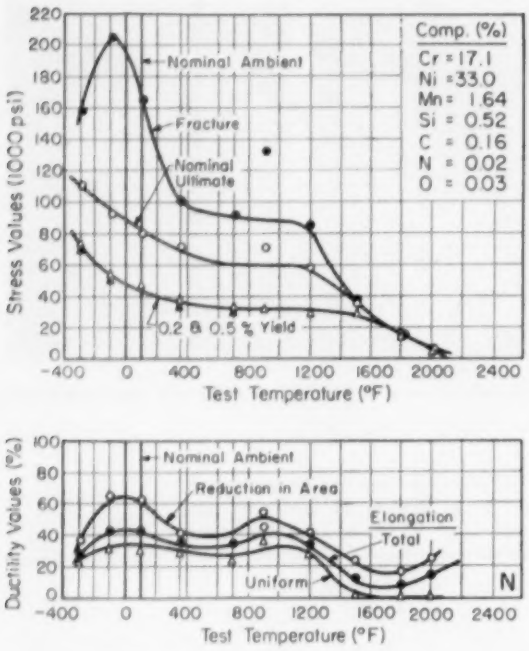


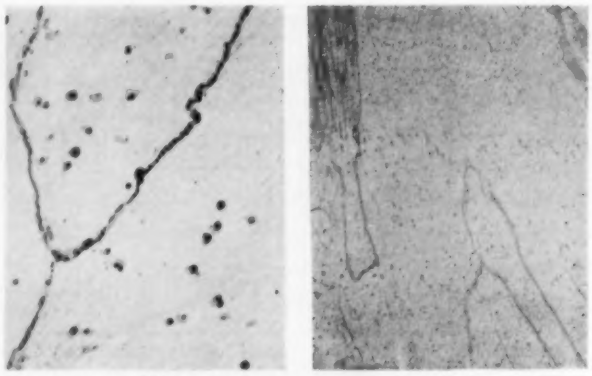


×2000 ×100

As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

Fig. 4 Influence of temperature upon short-time tension properties of austenitic type 310 weld metal (25Cr – 20Ni) as-deposited with covered electrodes





×2000 ×100

As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

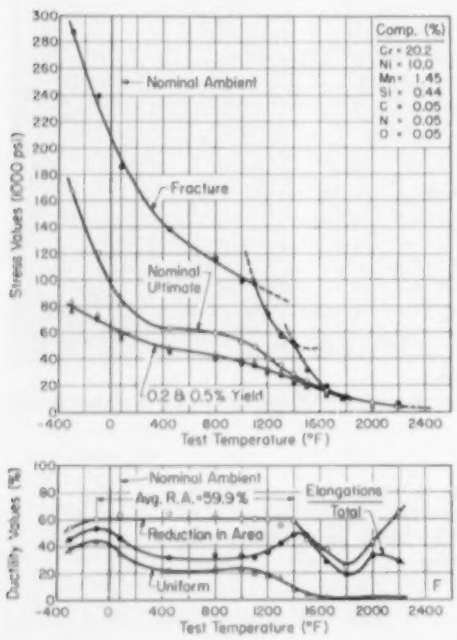
Fig. 5 Influence of temperature upon short-time tension properties of austenitic type 330 (17Cr – 33Ni) weld metal as-deposited with covered electrodes

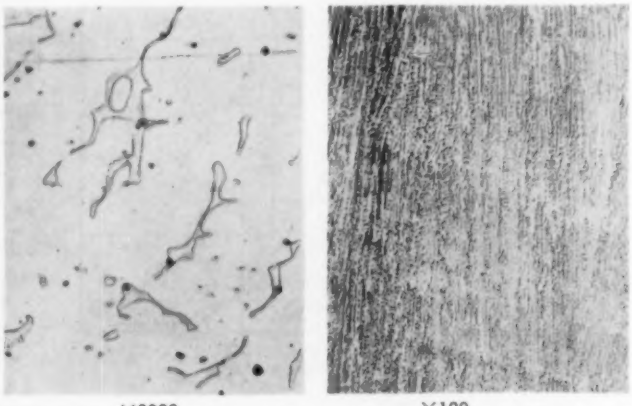
specially described the specimens were tension tested to rupture in the as-deposited condition over a temperature range which varied between the limits of −300 and +2200° F. Each specimen was individually brought up or down to test temperature while free of applied load, held for 20 min at temperature and then loaded to rupture at a strain rate of 750% per hour. All specimens at and above room temperature were loaded and ruptured in an air environment, those at subambient temperatures in an environment of gaseous or liquid nitrogen.

Continuously recorded load-deflection curves to rupture were secured for every specimen. Conventional tensile data were taken from these curves. No sharp yield points were observed for these metals, even at −300° F. A sample data sheet is shown in Table 3.

Chemical analyses were made of each weld, the samples being taken from the body of the lowest temperature specimen in each series. Oxygen analyses were made with the vacuum fusion technique at 1650° C except that the welds which contained titanium were heated to 2000° C.

Macrographic and micrographic studies were made of all unstrained as-deposited weld metals and in many

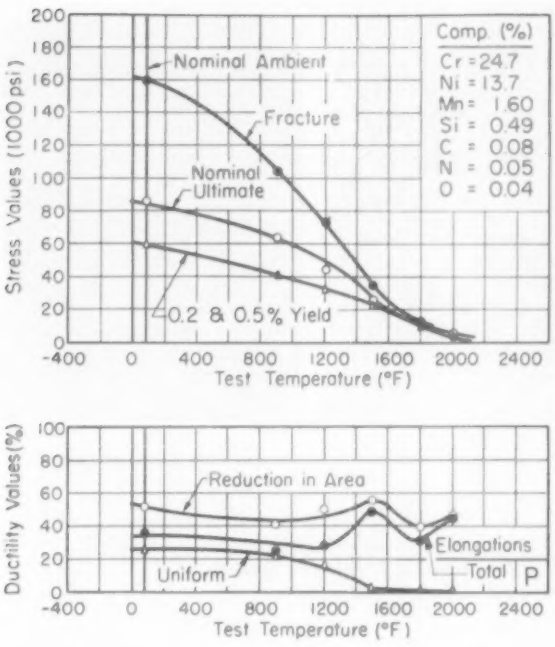


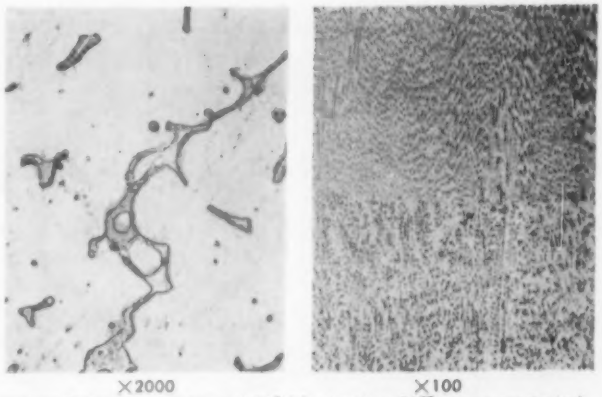


×2000 ×100

As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

Fig. 6 Influence of temperature upon short-time properties of 9% ferrite content type 308 18% Cr – 8% Ni weld deposited with covered electrodes





As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

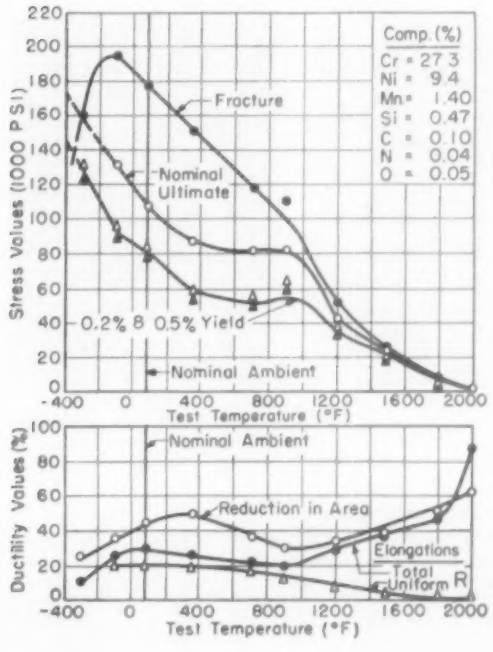
Fig. 7 Influence of temperature upon short-time tension properties of 9% ferrite type 309 (25Cr – 12Ni) weld metal as-deposited with covered electrodes

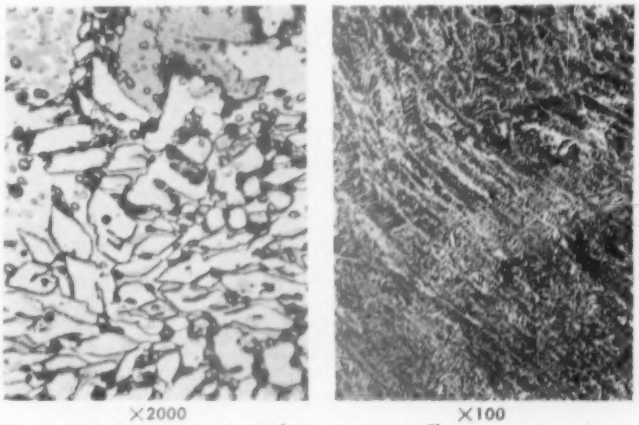
cases again after fracture. A few representative specimens were examined with the electron microscope up to ×30,000. X-ray diffraction patterns were also made of some of the welds to specifically confirm the basic f.c.c. and b.c.c. crystal structures.

Ferrite contents, estimated from Magne-Gage, and hardness determinations were both made at room temperature before and again after rupture at each test temperature on both the strained and unstrained portions of the specimen. Typical hardness data are shown in Table 3. As-deposited average ferrite contents are shown in Table 1. An illustration of the influence of temperature and strain upon measured ferrite for one weld is shown in Table 3.

Test Results

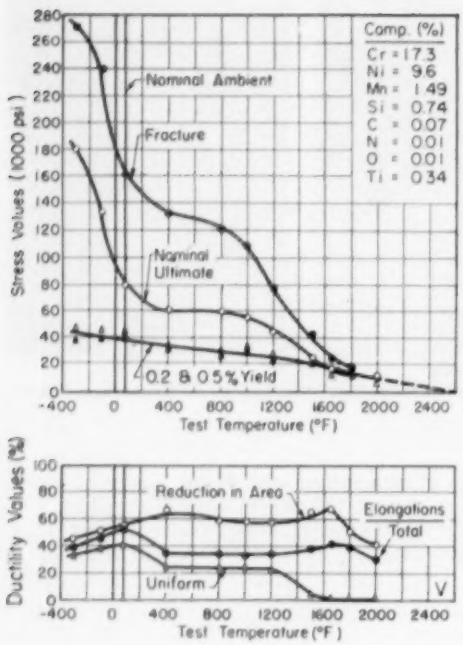
Chemical analyses of the weld deposits were shown in Table 1. In making covered electrodes sufficient chromium is usually added to the coatings to compensate for the minor losses from oxidization which occur during passage of the molten metal through the arc. The average compensated transfer efficiencies, for the plate dilution or enrichment conditions involved,

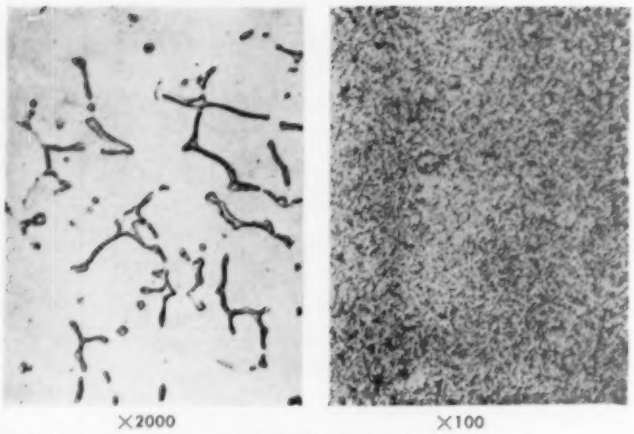




As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

Fig. 8 Influence of temperature upon short-time tension properties of weld deposited with covered electrodes. 27% Cr – 9% Ni





As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

Fig. 9 Influence of temperature upon short-time tension properties of 5% ferrite content type 321 weld metal deposited with argon shielded arc

for the several elements were:

Nitrogen—117%, that is, there was a slight pickup from the air through the arc shield.

Nickel—100%.

Chromium—97%.

Carbon—96%.

Manganese—91%.

Copper—86%.

Molybdenum—85%.

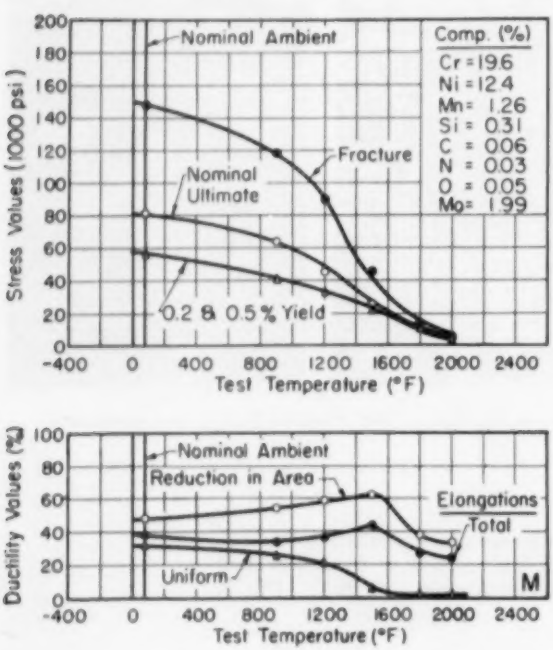
Phosphorus—70%.

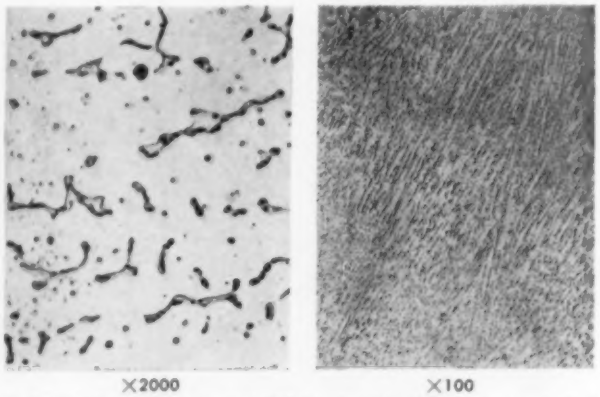
Silicon—Loss to gain depending upon individual coating, process or procedure used.

Oxygen—From 0.008 to 0.044%, that is, from 100 to 500% increase depending upon individual wire composition, coating, process or procedure used. This increase comes from the air surrounding the arc shield, from chemical reactions with components of the electrode coatings, and from plate and wire surfaces.

Niobium (= Columbium)—All added from coating of covered electrodes; 85% for commercial argon-oxygen shielding.

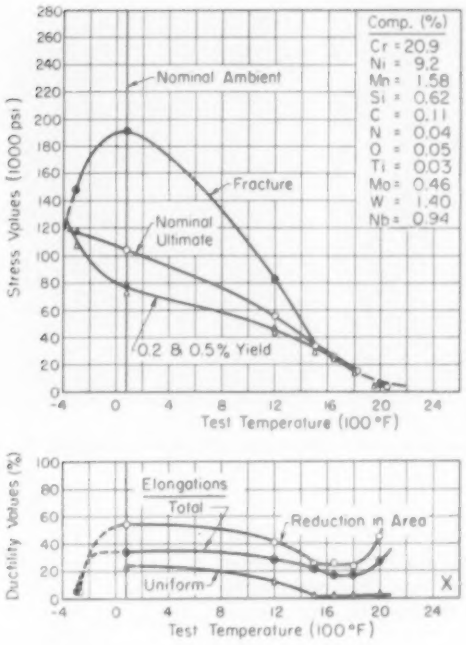
Magnetic measurements made on the deposits before and again after rupture showed the values of equivalent

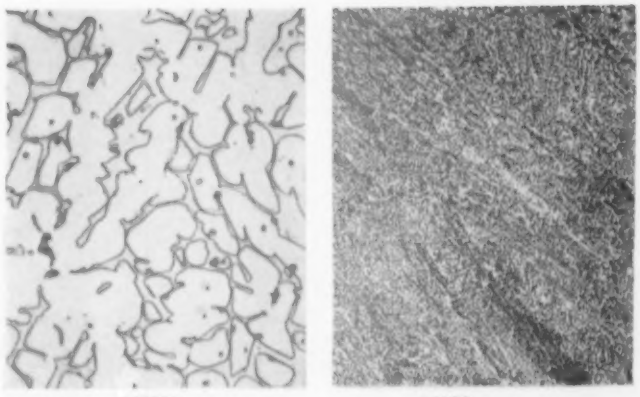




As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

Fig. 10 Influence of temperature upon short-time tension properties of 7% ferrite type 316 (20Cr – 12Ni – 2Mo) weld metal as-deposited with covered electrodes





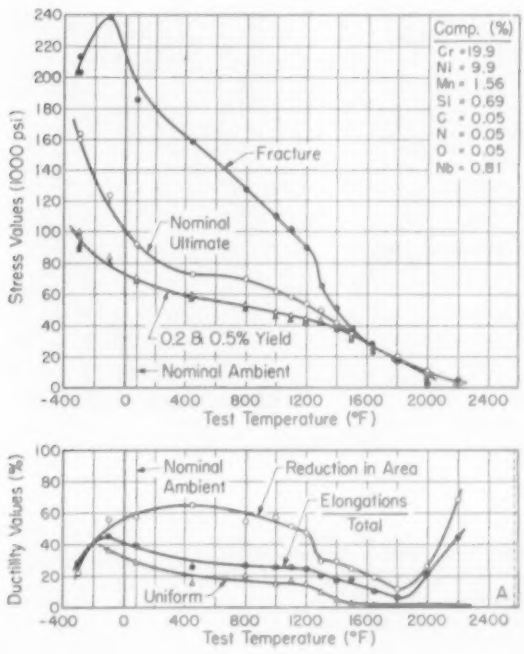
As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

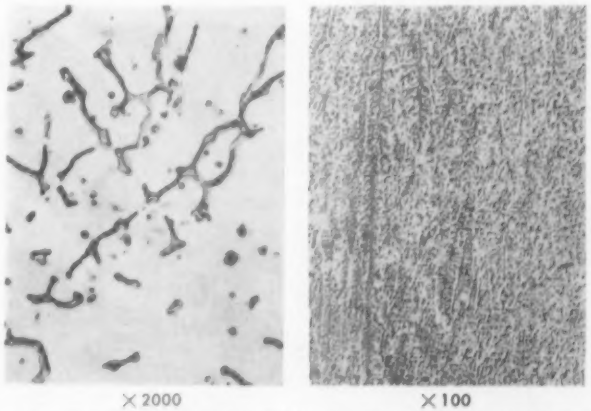
Fig. 11 Influence of temperature upon short-time tension properties of type 349 (Cr-Ni-W-Mo) weld metal as-deposited with covered electrodes

ferrite volume in the test welds at +80° F to range from 0.0 to 27% before straining. It was found that the center of the weld which was tension tested, Fig. 1, generally conformed, in the as-deposited condition, to within 2% of the equivalent ferrite content as calculated from the Schaeffler diagram, Table 1.[4] Under test conditions the ferrite content was influenced both by temperature and by straining, Table 3.

The macrographs and microstructures, in general, conformed to the as-cast dendritic or cored structures which are considered to be normal for as-deposited metal-arc weld metal. Except for the 2% Si – 25Cr – 20Ni weld, Fig. 3, all welds were free of cracks for the unrestrained conditions used and all fractures were free of porosity.

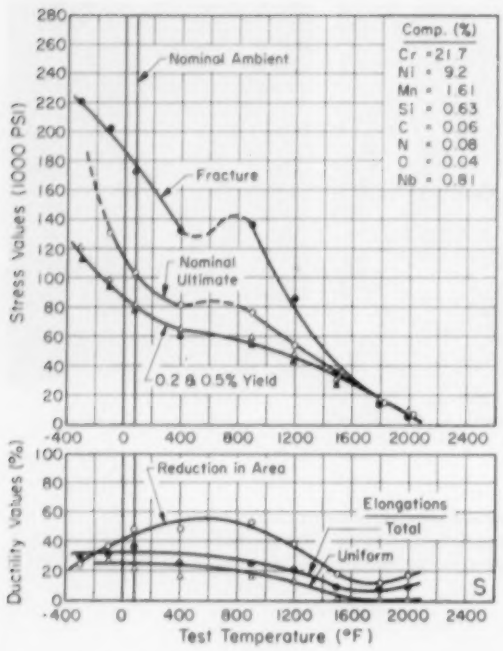
The micrographs of ×100 emphasize the dendritic patterns and the nonuniformities from bead to bead but these are not too useful in establishing basic phenomenon. For this reason all welds were re-examined at ×2000, which is about the upper limit of resolution with the optical microscope. This technique reveals the outlines of the delta ferrite in the two-phase compositions and likewise the contaminated grain boundaries of the fully austenitic welds, Figs. 3 to 16, inclusive.

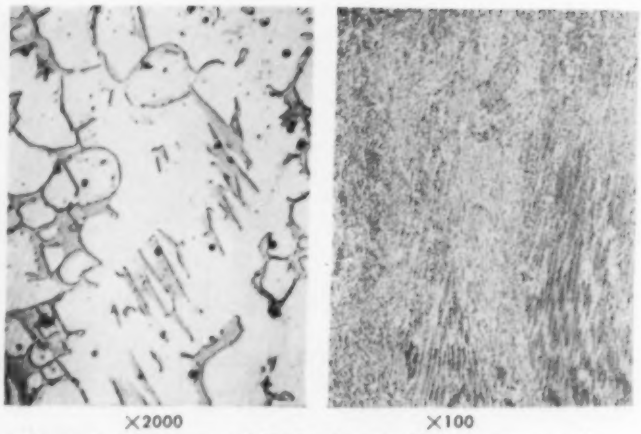




As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

Fig. 12 Influence of temperature upon short-time tension properties of 9% ferrite content 18% Cr – 8% Ni (plus niobium) weld deposited with covered electrodes





×2000 ×100

As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

Fig. 13 Short-time tension properties of 15% ferrite content type 347 weld metal deposited with covered electrodes

The tensile stress and ductility data obtained were plotted against temperature and six curves are shown for each of the welds. From top to bottom of Figs. 3 to 16, these are:

(*Upper Graphs*) 1. Fracture stress = load at initiation of final fracture divided by final cross-sectional area of the reassembled fracture.

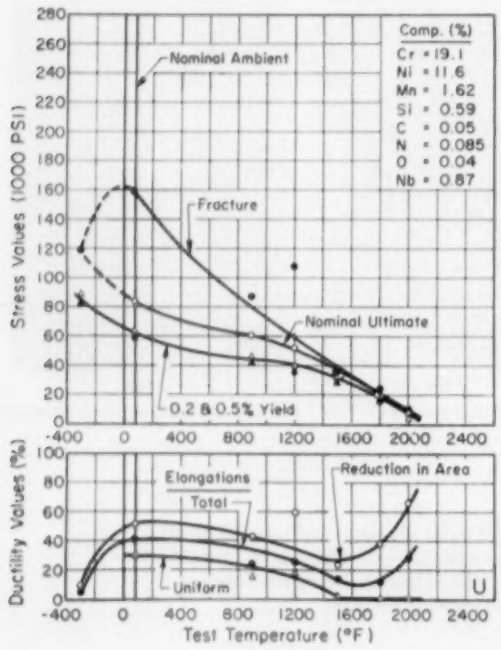
2. Nominal ultimate stress = maximum load resisted beyond 0.5% strain divided by original cross-sectional area (0.357-in. diam).

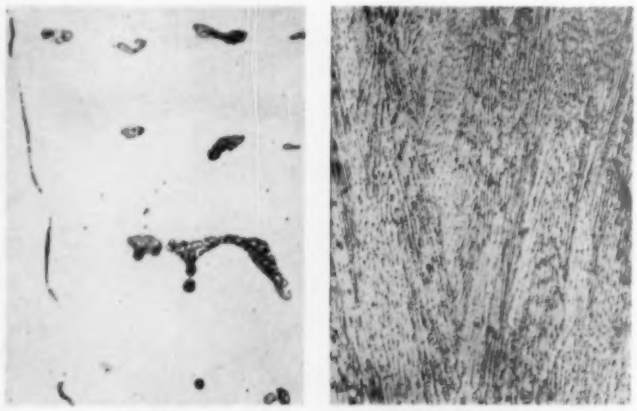
3. 0.2 and 0.5% yield stresses = loads at 0.2 and 0.5% strains measured by offset from the elastic straight-line portion of the stress-strain curve divided by the original cross-sectional area (0.357-in. diam).

(*Lower Graphs*) 4. Reduction in area = difference between final fracture area and original area (0.357-in. diam) expressed as a percentage of the original area.

5. Total elongation = permanent strain at final fracture in percent of original 1.5-in. gauge length.

6. Uniform elongation = strain in percent of 1.5-in. gauge length at occurrence of nominal ultimate load, that is, the strain corresponding to the point of zero slope of the nominal stress-strain curve. Strains less than the uniform values shown are about equally dis-





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As-deposited microstructures at +80° F (reduced by 50% upon reproduction)

Fig. 14 Short-time tension properties of austenitic type 347 weld metal deposited with covered electrodes

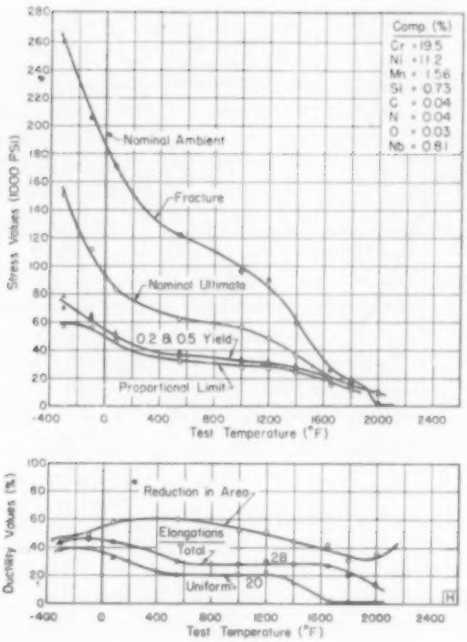
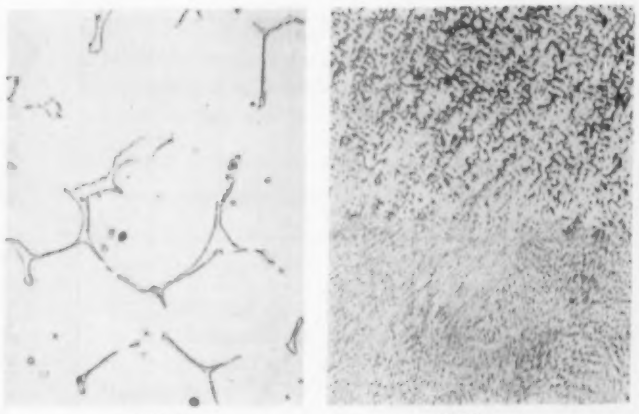


Fig. 15 Influence of temperature upon short-time tension properties of type 347 electrode argon shielded weld metal as-deposited



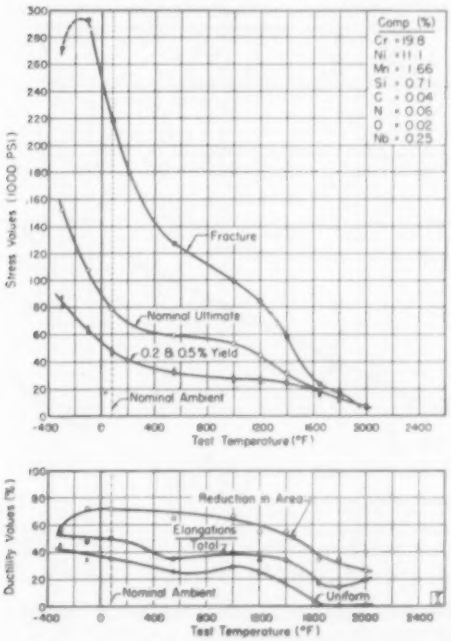
As-deposited microstructures at + 80° F (reduced by 50% upon reproduction)

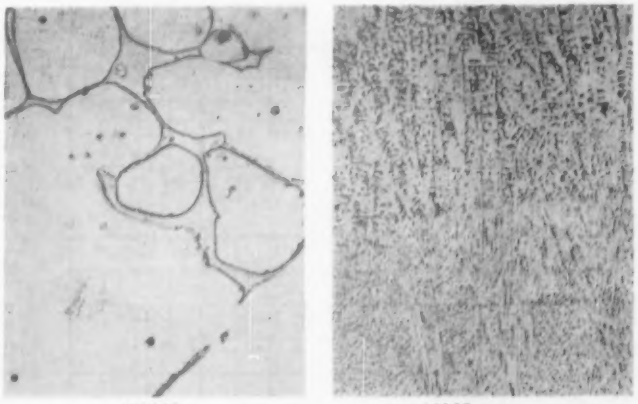
tributed along the gage length.

The key components of the compositions individually listed in these figures relate to the weld metal only.

Discussion

Except for the 27Cr – 9Ni weld metal, Fig. 8 (AISI Type 312, Series "R"), the Cr-Ni steel welds being described show, in varying degrees, a common characteristic of losing both strength and ductility as temperature increases above ambient up to around 1800 or 2000° F. Above 1800° F the strengths tend to continue to decrease toward zero as a lower limit as the metal approaches the melting point but in that range the ductility sometimes tends to rise, often by substantial amounts, Fig. 12. The ductility minima near 1800° F need not always be due to the presence of a molten eutectic but may be due to the presence of a weakened grain boundary or subgrain boundary caused by a micro- or submicroscopically thin film which can either diffuse into the matrix, pass into solution or change in form at the higher temperatures. The presence of low orders of ductility substantially below the freezing temperature was consistently found for the austenitic structures and for *some* of the welds containing niobium. These low orders of elongation were secured, in the individual instances shown, by





As-deposited microstructures at + 80° F (reduced by 50% upon reproduction)

Fig. 16 Influence of temperature upon short-time tension properties of 5% ferrite content (at + 80° F) 18% Cr – 8% Ni weld deposited with argon shielded metal arc

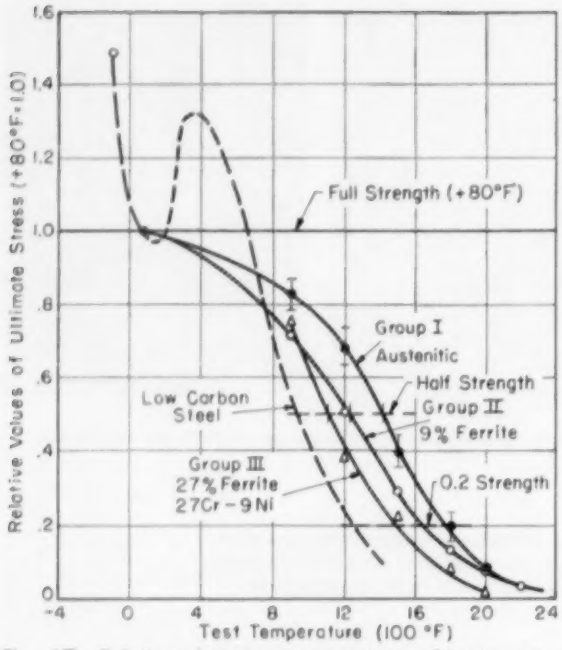


Fig. 17 Relations between temperature, ultimate stress and initial ferrite contents for Cr-Ni welds (without niobium)

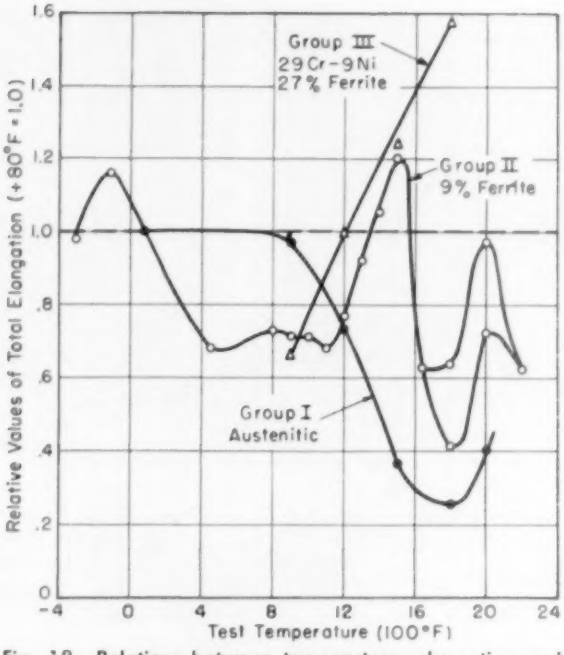


Fig. 18 Relations between temperature, elongation and initial ferrite content for Cr-Ni welds (without niobium)

the use of unnotched tensile specimens. Secondary fissuring was also shown to occur at and above 1500° F back of the fractures even on the low total elongation specimens. Gross cracking was observed to occur during the making of the welds with the unrestrained conditions used only for the test welds containing 2% silicon, 25% Cr and 20% Ni, Fig. 3.

Over-all the welds follow a normal metal strength pattern in that as they approach closer to the fully austenitic condition they tend to retain their strength

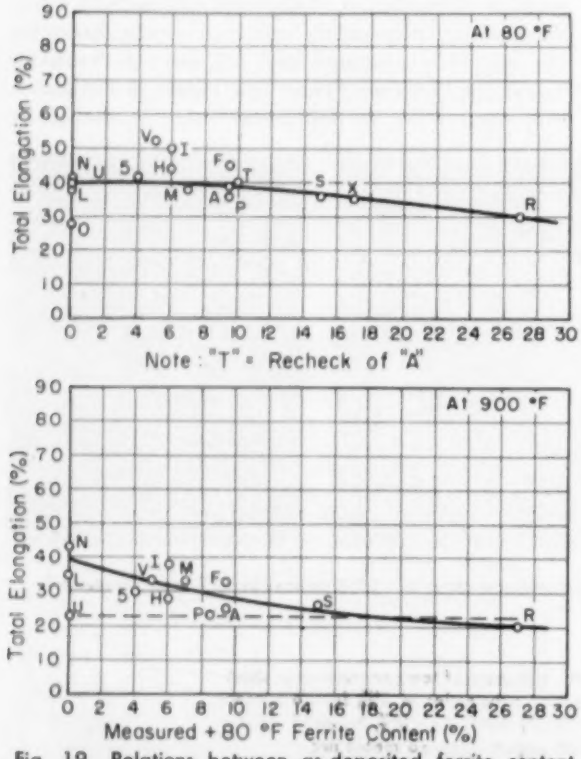


Fig. 19 Relations between as-deposited ferrite content at +80° F and total elongation at +80 and +900° F

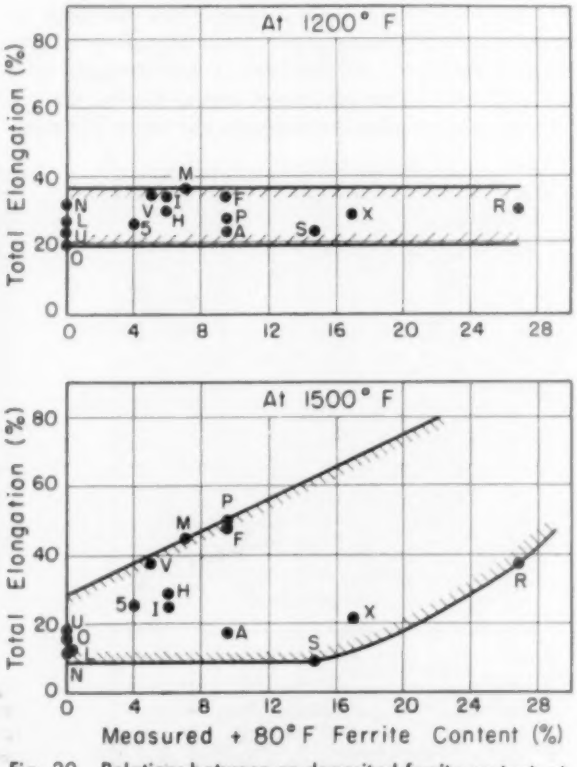


Fig. 20 Relations between as-deposited ferrite content at +80 F and total elongation at 1200 and 1500° F

to higher temperature levels and vice versa, Fig. 17.[5]

Early observations led to the conclusion that some austenitic type weld metals were crack sensitive and that such sensitivity was reduced by adjustment of composition to provide small amounts of ferrite in the austenitic matrix.[6] This now widely held belief is not substantiated by an analysis of the experimental data of Figs. 3–16. However, because of the widespread acceptance of the controlled ferrite content concept, the data will be discussed in five groups: the first three of increasing ferrite content within the plain Cr-Ni composition family and the last two of varying ferrite contents in the alloyed Cr-Ni composition family. This approach also simplifies the presentation of the interrelations of the 15 compositions being reported.

Plain Cr-Ni Steel Welds

Group I—Austenitic Structures. At the 1800° F test temperature no high ductility welds were secured with existing commercial electrodes when the as-deposited structure was austenitic at room temperature. As the initial structure of the plain Cr-Ni steel welds approached the fully austenitic condition the total elongation approached a minimum, Fig. 18; a reverse of the condition found for strength, Fig. 17. From the microstructures and tensile data it was postulated that the austenitic structures, Figs. 3, 4 and 5, are brittle at the high temperatures, and therefore crack sensitive, not because they are austenitic at room temperature but rather because when they are austenitic at room temperature the grain matrix is relatively strong at such temperatures as 1800° F, Fig. 17. This permits the imposition of stresses upon the contaminated grain boundaries beyond their weakened cohesive capacity

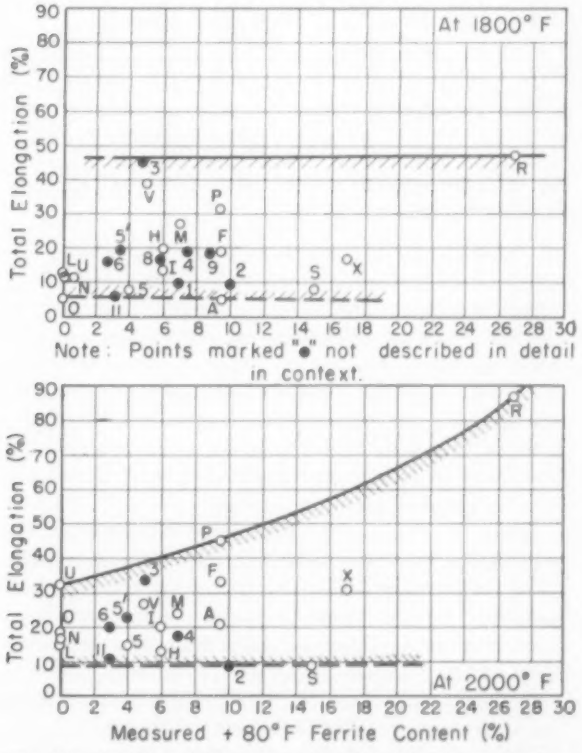


Fig. 21 Relations between as-deposited ferrite content at +80° F and total elongation at 1800 and 2000° F

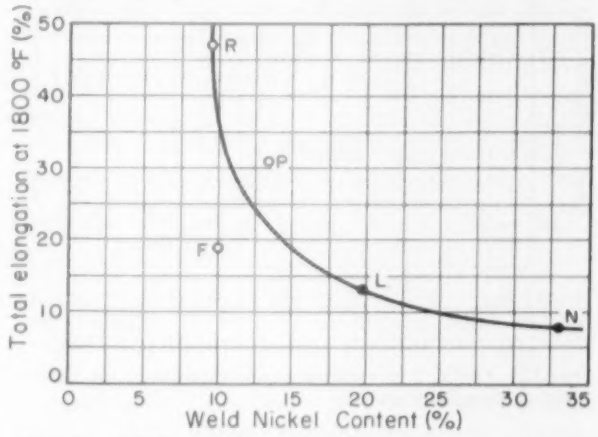


Fig. 22 1800° F elongation and nickel content relations for plain Cr-Ni steel welds

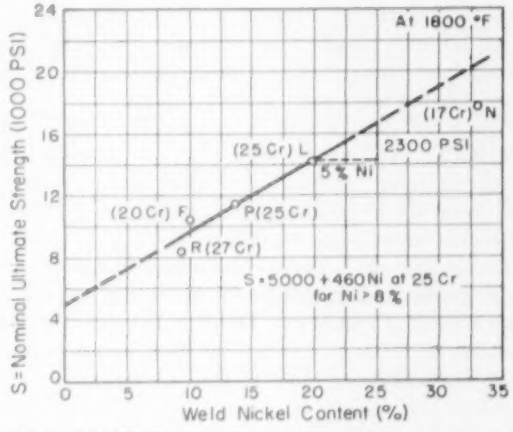


Fig. 23 1800° F strength and Ni content relations fo plain Cr-Ni steel welds

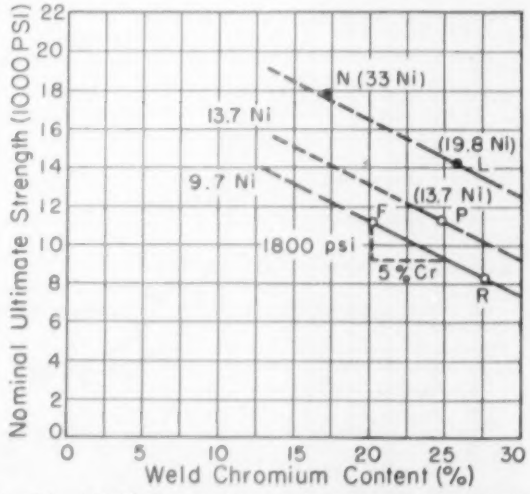


Fig. 24 1800° F strength and chromium content relations for plain Cr-Ni steel welds

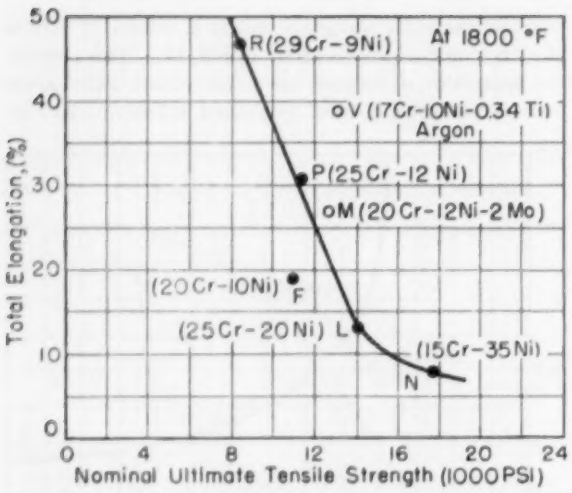


Fig. 25 1800° F strength-elongation relations for Cr-Ni steel welds without niobium

to resist. If the grain boundaries were to be made microscopically clean, it is presumed that these welds would be ductile. Achievement of microscopically clean, austenitic grain boundaries in as-deposited weld metal is not a simple task. Cleaner core wires, minimization of contaminates from electrode coatings and more efficient arc shielding are required.

Group II—9% Ferrite Content. The 20Cr – 10Ni and 25Cr – 14Ni welds, Figs. 6 and 7, contained 9% ferrite at room temperature. They were less strong and more ductile at the higher temperatures than the austenitic welds, Figs. 4 and 5.

Group III—27% Ferrite Content. The 27Cr – 9Ni weld, Series R, Fig. 8, was the hardest, strongest and least ductile at and below +900° F and was of average ductility at 1200° F. It was the least strong and most ductile at and above 1800° F, Figs. 17 to 21.

While the plain Cr-Ni steels thus tend to show a proportional relationship between initial room-temperature ferrite content and high-temperature ductility

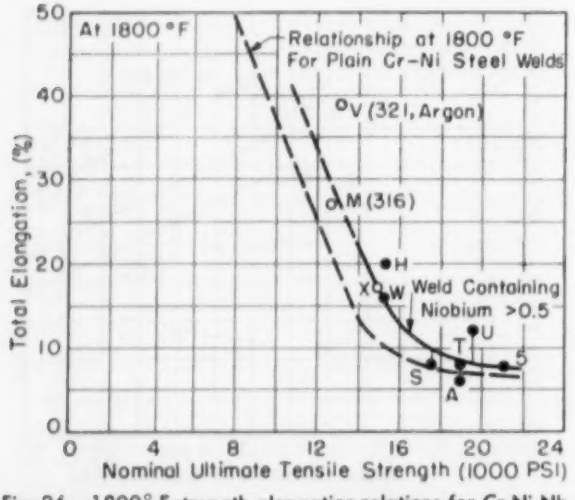

At 1800 °F
Relationship at 1800 °F For Plain Cr-Ni Steel Welds
V (321, Argon)
M (316)
Weld Containing Niobium >0.5
Total Elongation, (%)
Nominal Ultimate Tensile Strength (1000 PSI)

Fig. 26 1800° F strength-elongation relations for Cr-Ni-Nb steel welds

there is no single relation between total elongation or reduction of area secured at rupture and the initial ferrite content at room temperature when all compositions are considered, Figs. 19 to 21.

Alloyed Cr-Ni Steel Welds

Group IV—Titanium and Molybdenum Additions. The use of supplementary alloying elements such as titanium and molybdenum in the base metal has been common practice for many years. For a given high-temperature strength these welds generally result in improved high-temperature ductility, the inert-gas-shielded Type 321 weld V of Fig. 9 being about as good as can be produced at the present state of knowledge. Earlier it was impractical to produce this type of electrode in the covered form because of the high titanium loss from oxidation in passing across the arc.

In contrast to the plain Cr-Ni welds just described, the argon-shielded titanium-bearing weld of Fig. 9 has a ductility, as judged by either reduction in area

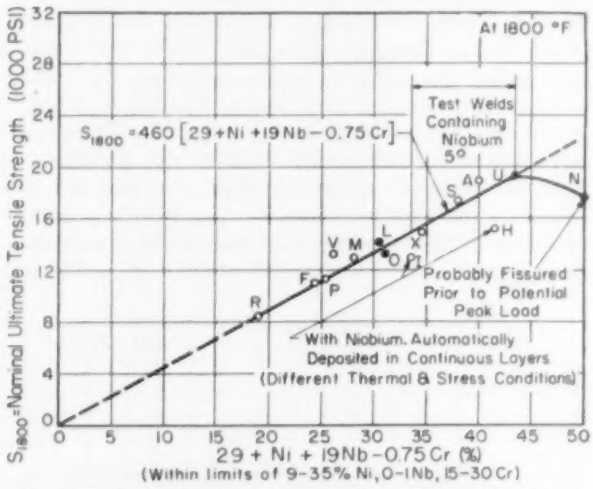

At 1800 °F
Test Welds Containing Niobium 5°
$S_{1800} = 460\,[29 + Ni + 19Nb - 0.75Cr]$
Probably Fissured Prior to Potential Peak Load
With Niobium, Automatically Deposited in Continuous Layers (Different Thermal & Stress Conditions)
S_{1800} = Nominal Ultimate Tensile Strength (1000 PSI)
29 + Ni + 19Nb – 0.75Cr (%)
(Within limits of 9-35% Ni, 0-1Nb, 15-30 Cr)

Fig. 27 Strength composition relations for as-deposited Cr-Ni steel metal-arc weld metals

or total elongation, which is nearly independent of temperature across the range from −300 to +2000° F. Detail trends toward lowered ductility exist at both the lower and upper extremes of temperature but very good ductility remains at both of those extremes. The location of the yield stress curve with respect to the ultimate and fracture stress curves is of particular interest, especially at the lower temperatures.

The Type 316 covered electrode weld "M" of Fig. 10 also exhibited good hot ductility.

Group V—Niobium (=Columbium) Additions. The AISI 347 welds, characterized by their niobium content, have been widely used recently for medium-high temperature service. Some cracking experiences have been reported.[7] The test welds, Figs. 11 to 16, inclusive, clearly indicate the source of defection found in some instances is again the low ductility which is again centered around 1800° F. Total elongations as low as 6% were secured, Fig. 12. This phenomenon has not been recognized by the industry. Best results

were secured with inert gas shielding, Series H, Fig. 15, by Mo-W additions, Series X, Fig. 11, and in general when lower niobium, oxygen and silicon contents were used.

Source of 1800° F Brittleness

It is apparent that a new approach to the solution of the high-temperature brittleness problem is necessary. If a mechanism common to all welds of this type could be established to show that the matrix strengthening and the grain or subgrain boundary weakening features both contribute to the high-temperature brittleness, a clearer understanding of the cracking problem would at once be available. Toward this end special attention was devoted to a study of the 1800° F strengths and ductilities, since this consistently appears to be about the center of the critical temperature range for all the commercial compositions subject to this defection.

By arranging the 15 test weld compositions of Figs. 3–16 in increasing orders of ductility at 1800° F, Table 1, and inspecting the data in series of descending orders of the amount of each alloy content, it was observed that for other than the key elements of Cr and Ni, silicon and niobium appear to be likely elements involved in causing the loss of high-temperature ductility with lesser effects being caused by other elements. A complicating factor is that with fairly wide Ni, Cr, Nb and Si variations, both relatively good and poor performances were secured with both larger and smaller quantities of the four elements, an exception being that ductile welds at 1800° F were not secured with high nickel contents.

A fairly smooth, uniform relation of decreasing ductility with increased nickel contents was obtained by plotting nickel content for the plain Cr-Ni welds against total elongation at 1800° F, Fig. 22. The function of the nickel, however, is to tend to provide the stronger austenitic form of the metal, and it can be shown that for the five plain Cr-Ni compositions, Figs. 4 to 8, inclusive, the strength increases uniformly and substantially linearly with nickel content, Fig. 23. Each percentage addition of nickel increases the strength by an average of 460 psi. For a given nickel content the titanium (AISI 321, Fig. 9) and the molybdenum (AISI 316, Fig. 10) bearing welds are slightly stronger.

The lower nickel content weld contained the most chromium and the highest nickel one contained the least chromium. For the plain Cr-Ni steel welds the 1800° F strengths are inversely related to the chromium content, Fig. 24, each percentage addition causing an average decrease of 360 psi.

There is a generally inverse relationship between strength and ductility at 1800° F for the plain Cr-Ni compositions, Fig. 25. Other factors cause variation in this relationship. By redrawing the same strength-elongation curve it can be shown that most of the alloy-enriched compositions fall on a different curve displaced upward on the ductility scale, Fig. 26. Therefore, for a given strength at 1800° F the alloy-enriched Cr-Ni steel compositions, in general, have improved hot ductility. However, all the highest strength (over 16,000 psi) welds at 1800° F are brittle at that temperature, that is, the total elongations are less than 12%, Figs. 25 and 26.

From a detailed examination of high-temperature strengths, it is clear that niobium also has a potent effect upon the 1800° F strength. For the nickel-chromium contents studied, Table 1, a 1% niobium addition provides an average increase in tensile strength of 8900 psi at 1800° F, which is the average equivalent of 19% added nickel. This average ratio was derived from comparisons of strength plots for appropriate Cr-Ni content welds, as in Fig. 24, and considering the plus variance from the corresponding Cr and Ni values which was always found to be present as being wholly due to niobium. With these detail coefficients the 1800° F strength of the as-deposited weld metal was expressed as a function of nickel, niobium and chromium contents, Fig. 27. The coefficients shown can be applicable only for the conditions

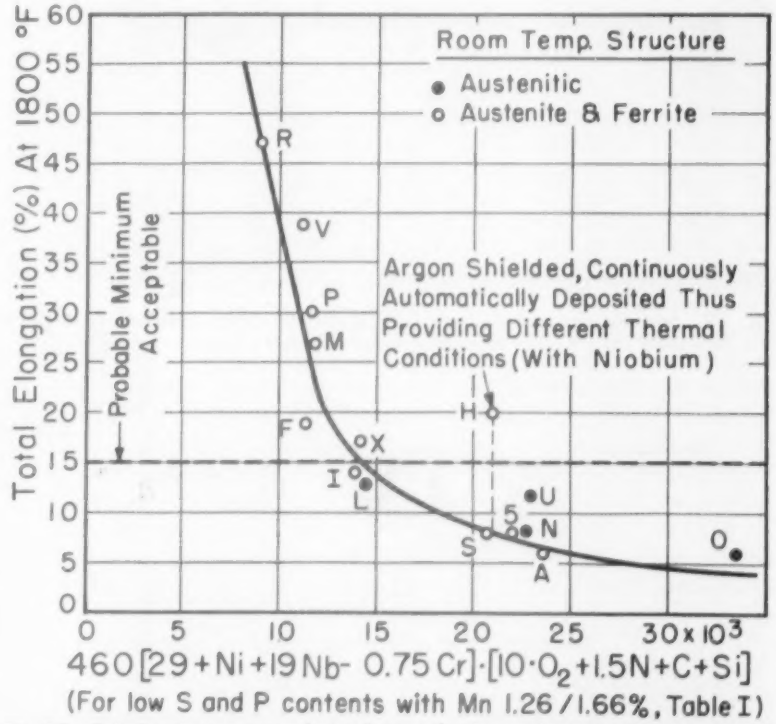


Fig. 28 Relations between products of strengthening and segregating components of compositions and 1800° F elongation for AISI 300 series as-deposited weld metal

wherein an austenitic matrix is produced. These correlations can only apply to weld manganese contents of the order involved in the tested range being reported, that is, from 1.26 to 1.66% and for low (0.015%) sulfur and phosphorus contents. The excellent results secured with manganese contents of about 4% will be reported later.

The experimentally secured elongations at 1800° F were plotted against the product of the abscissa of Fig. 27 (i.e., the strengthening or grain and subgrain boundary stress-imposing factors), and the sum of the carbon, silicon, nitrogen and oxygen contents (i.e., the boundary-weakening factors), the last two with coefficients of 1.5 and 10, respectively, Fig. 28. The coefficients for oxygen, nitrogen, carbon and silicon are empirical and were selected by trial and error to secure the best fit with the data available. Following this procedure there was only one exception to a smooth curve. The nonconforming point (H) was for an inert-gas-shielded weld (Fig. 15) deposited in four continuous layers instead of seven stringer beads, Table 2. This resulted in different thermal and internal stress conditions. It will be shown that heat treatment results in a further decrease in strength and an increase in high-temperature elongation.

Experience has taught the delicacy of placing undue reliance upon empirically derived relationships but pending receipt of further knowledge and understanding, which is actively being sought, it is indicated that the direction for improvements in high-temperature ductility of as-deposited metal-arc weld metals and freedom from fissuring and cracking in the present Cr-Ni steel type welds under the highly stressed conditions which exist in massive, restrained and curvilinear structures lies in:

(*a*) Altering compositions to provide the lowest appropriate strength at temperatures from only slightly below the solidus down to just over 1200° F. This may be done by holding nickel and niobium to suitable minima and in manganese content ad-

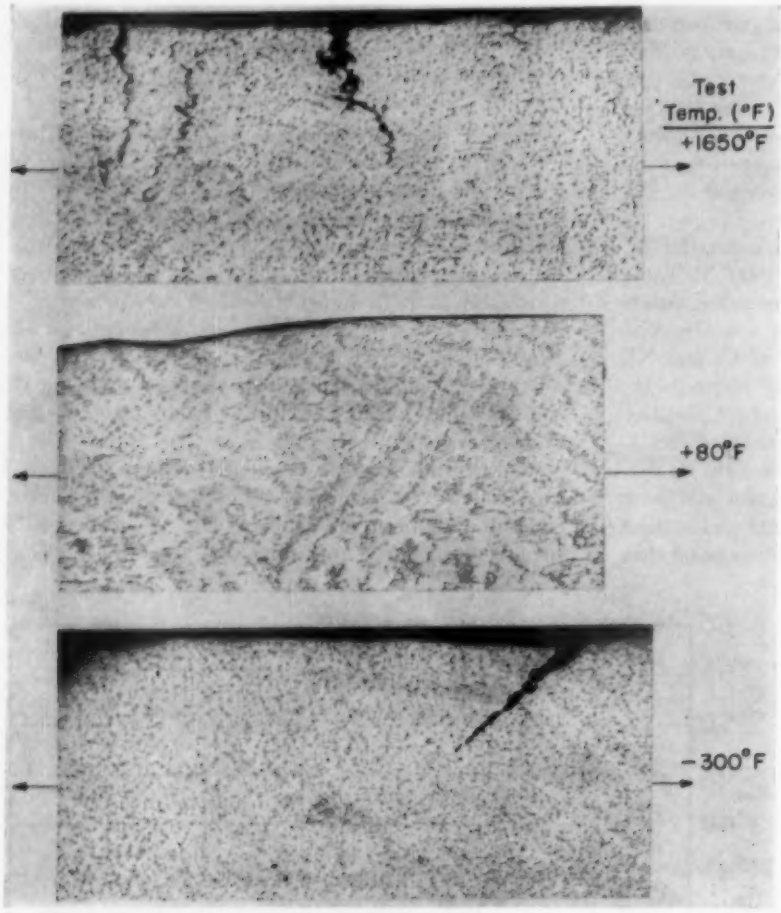


Fig. 29 Microfissures and structures of 0.25% Nb argon shielded weld metal "as deposited" and loaded to rupture at temperatures shown. (×100)

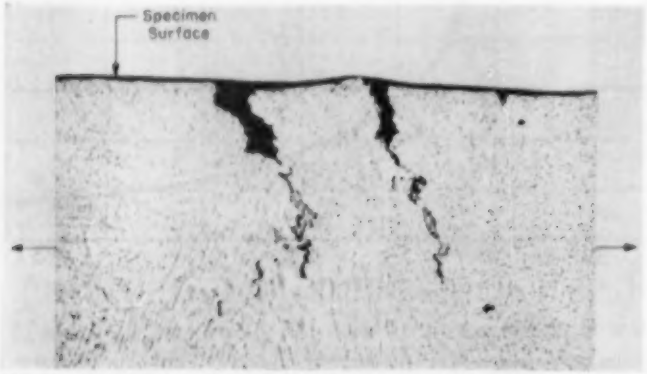


Fig. 30 Fissures in 0.81 Nb argon shielded weld loaded to rupture at +1800° F

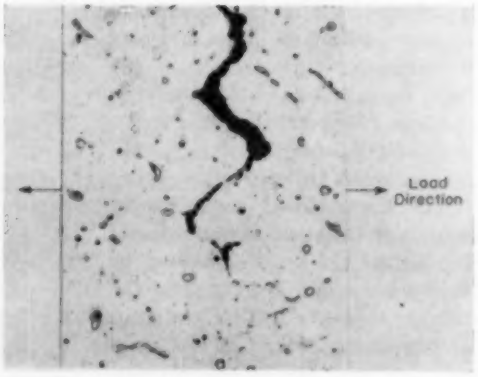


Fig. 31 Fissure propagation at ×2000

justments. The data indicate that high-temperature strength decreases can also be achieved by chromium additions, but the probability for formation of the brittle sigma phase is then increased.

(*b*) Decreasing the amounts or altering the distribution or form of the boundary weakening elements present. These include silicon, carbon, nitrogen, oxygen, sulfur and phosphorus.

The use of inert gases with low impurity content electrode wires is one of the more promising possibilities for securing lowered weld impurity contents but neither the use of inert-gas shielding or low impurity content wires alone are adequate.

All welds studied except the V series, Fig. 9, contained substantial quantities of nitrogen, not only because of inadequate are shielding but because of the art followed in producing the steel used in the original wires. These higher nitrogen contents did not result in weld porosity as for low-carbon steels[8] because of the higher solubility of nitrogen in chromium-bearing steels.[9] The commercial wire used in making the weld V, which had excellent high-temperature ductility, contained lower oxygen (0.005%), nitrogen (0.006%), phosphorus (0.005%) and copper (0.014%) than any of the other 14 electrodes used. This, in combination with an effective argon shield around the arc, resulted in an inherently cleaner weld deposit, Fig. 9, which could both develop and resist higher stresses at the higher temperatures which every multipass weld must undergo at least once and it could flow under these high stresses without fissuring. This sample contained the second highest (0.74%) silicon content of any weld in the series.

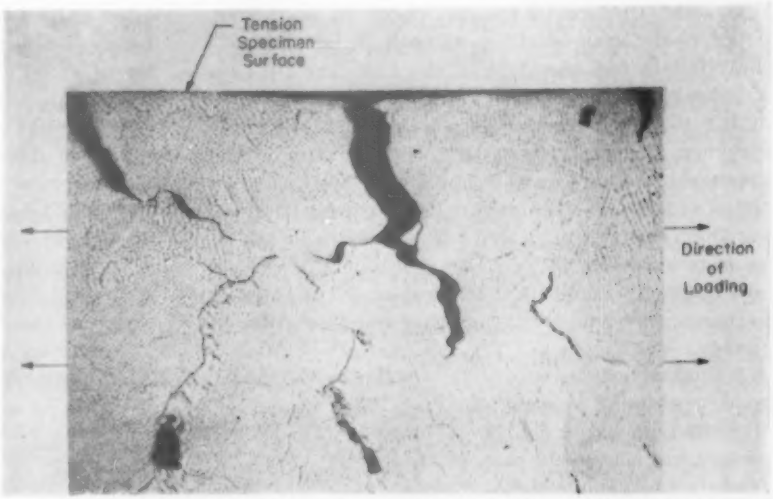
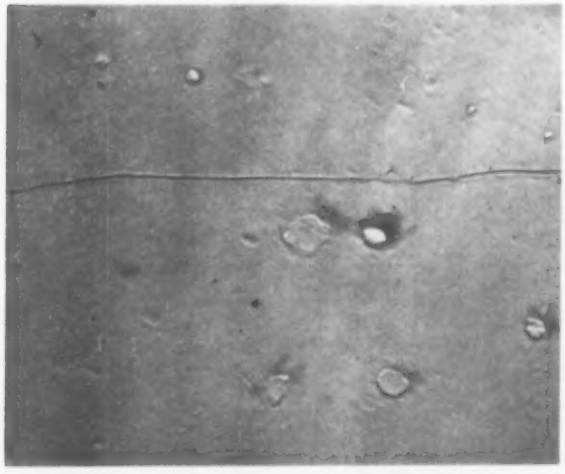


Fig. 32 Grain boundary failure of austenitic compositions. (Example shown is 25Cr – 20Ni but is also typical of 15Cr – 35Ni, and 25Cr – 20Ni – 2Si grades)



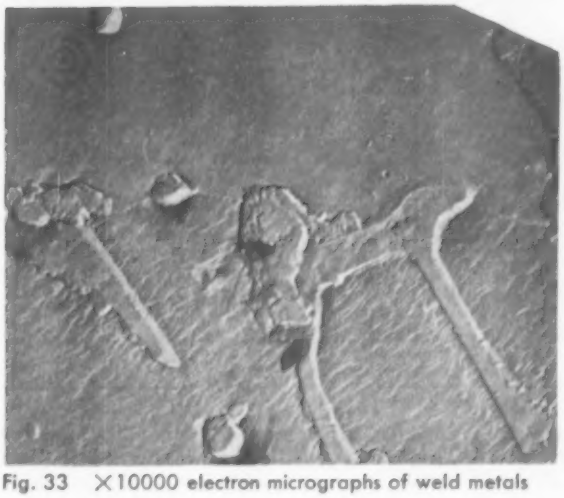


Fig. 33 ×10000 electron micrographs of weld metals

Microfissuring

Whether or not service cracks are caused only by the presence of microfissures formed during welding is a subject of controversy.[10] The test data reported herein indicate that for some known unsuitable experiences the initial weld structure and composition and therefore the probable properties were such that microfissuring may indeed have been present from the time of first solidification of the weld metal in a massive, restrained, curvilinear structure wherein the low strength and ductility metal at the high temperatures was forced to absorb the full strain caused by local movements during the welding of the base metal which was stronger at its lower temperature and with its rigid mass. However, the data show with equal clarity that initial fissuring need not be present to cause brittle failure under substantial strains at the higher temperatures. Figure 29 is an illustrative example from Weld I, Fig. 16. The center micrograph, taken longitudinally through a fractured room-temperature tensile specimen just back of the fracture, shows flowed metal which remained free of fissuring even under rupturing stresses

at that temperature. The lower photo, from a −300° F test of the same weld, shows both an incipient 45° shear failure and the start of the final fracture as a 45° shear type failure which progressed independently of the two-phase constituents. This highly stressed specimen, Fig. 16, was also free of microfissures. The upper photo shows another specimen from this weld, tested at 1650° F, with random local fissuring progressing from cluster to cluster of ferrite with the axis of propagation being 90° to load direction. This weld was originally sound until strained above its capacity at the higher temperatures within the short time of the test.

A similar phenomenon at 1800° F in an argon-shielded weld containing higher (0.81%) niobium is shown in Fig. 30. This section was also made back of the fracture and the line of major propagation is again normal to the direction of application of tensile stress. The cracks move from cluster to cluster of metal which is ferrite at room temperature. Propagation of an 1800° F fissure in the two-phase structure of weld 5, Table 1, at ×2000 is shown in Fig. 31. In contrast, the austenitic structures fail at the elevated temperatures along the boundaries of the grains or subgrains or both, Fig. 32. While the general progress of fissuring and cracking is again normal to the direction of loading, individual cracks may turn as much as 90° with the grain boundary. Such fracture surfaces appear to be woody or fibrous.

Secondary surface fissures are generally prevalent in all of these fractured weld metal tensile specimens at all temperatures from 1500° F and higher. A bend test at controlled high temperatures would therefore probably be a suitable means for rapid evaluation of crack susceptibility. Also, welding of test parts under dynamic strain can be used to demonstrate this phenomenon. Such tests, however, do not provide the control or the data as secured with the tension tests.

Electron micrographs at ×10,000 and higher for welds in the as-deposited unstrained condition further tend to confirm the relation between good hot ductility and relatively clean grain boundaries, Fig. 33. Poor hot ductility relates to unclean or otherwise disturbed grain boundaries, as by a continuing second phase. A true microfissure is also shown in the lower photograph of that figure.

Notch Effects

During the making of a weld, sharp notches often exist between beads and the interface plate wall and the weld bead. These cause local concentrations of stress and strain. A metal which can strain only 6% under uniform conditions at 1800° F, Fig. 12, can withstand little total deformation in the notched condition at that temperature where from most to all of the straining occurs at the root of the notch. Even when the metals are not notch sensitive by definition,

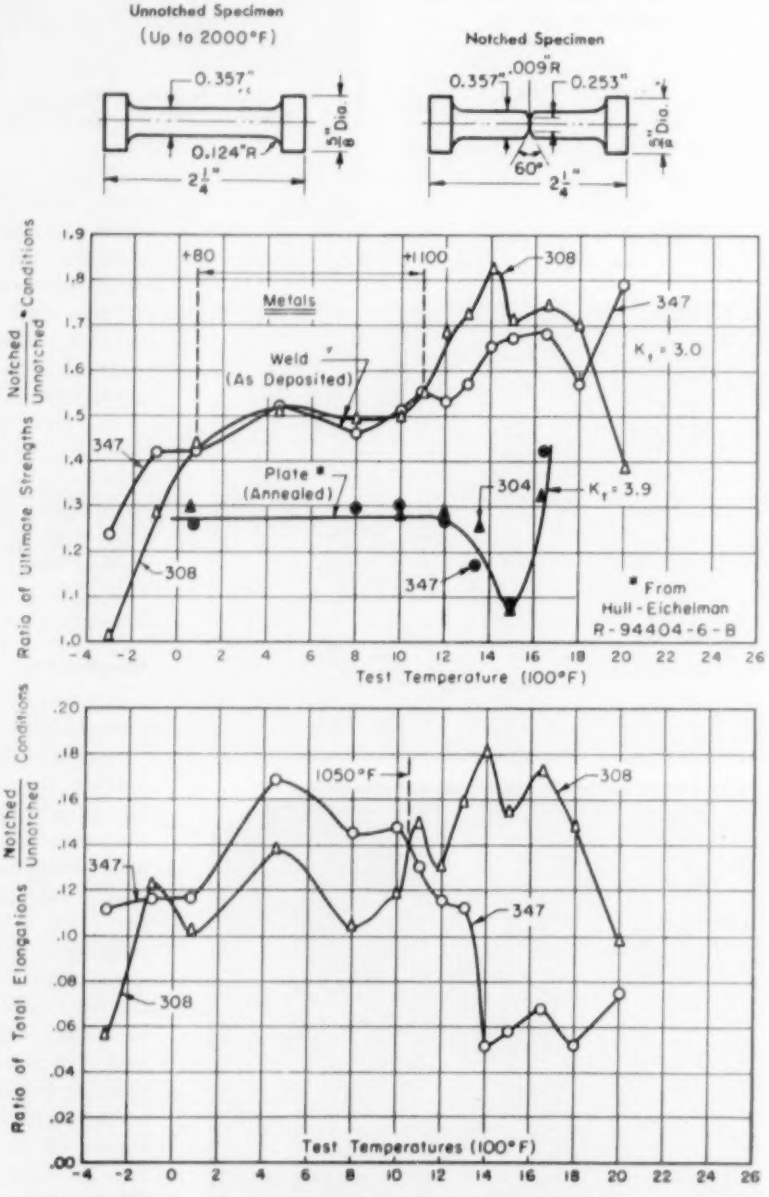
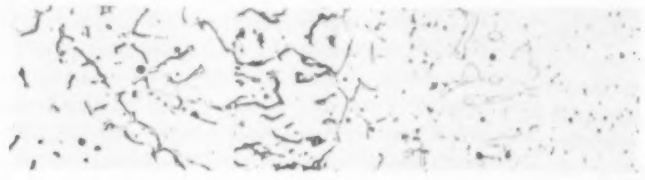


Fig. 34 Evaluation of notch properties of covered electrode arc deposited 18Cr–8Ni type weld metals (9% ferrite at +80° F) based upon conventional use of stress and also upon use of strain

that is, when the capacity to withstand tensile load per unit area is not reduced by the presence of a notch, the potential for failure is increased by the presence of the severe inherent limitations on local straining at elevated temperatures. This is further influenced by the fact that even in unnotched specimens maximum load in these weld metals in the as-deposited condition is reached at a total elongation of less than 1% at test temperatures above 1650° F, Figs. 3–16. Beyond this amount of strain at such temperatures the metals flow only under the impetus of near maximum stresses until strain limited rupture occurs from fissure to fissure.

Availability of some hot ductility, that is, local capacity to flow at all temperatures between the solidus and the ambient, is a prerequisite to the production of fissure-free welds under notched and restrained conditions, the amount of flow required being a presently undefined variable depending upon the degree of restraint. From Fig. 28 a value of 15% at 1800° F appears to be a desirable minima. Because restraint is more severe in massive parts, most production cracking experiences are encountered with such products when using electrodes providing welds of high hot strength (more than 16,000 psi at 1800° F) and low high-temperature ductility (less than 15% at 1800° F). Best short-time hot ductility results have been secured in unnotched specimens with covered electrodes (up to 45% at 1800° F) with type 307 deposits containing 4% Mn and 0.9% Mo, point "3," upper plot of Fig. 21. These results will be described in detail in a later report.



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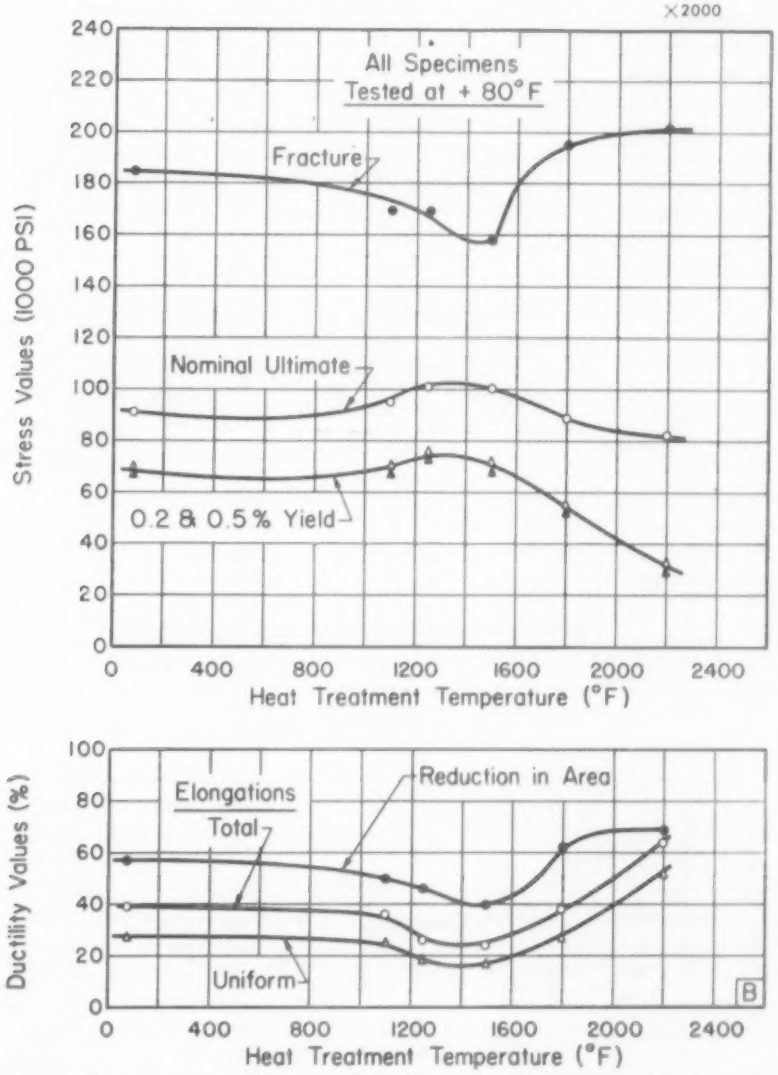


Fig. 35 Influence of temperature of annealing upon short-time +80° F tensile properties of 18Cr – 8Ni plus niobium weld metal (4-hr. hold time, furnace heat and cool. Argon atmosphere).

The relative responses of two commonly used welds to stress and strain under notched and unnotched conditions are shown in Fig. 34. The notched metals are duplicates of welds F and A of Figs. 6 and 12 and Table 1 which are used as a reference in securing the ratios in the two ordinates shown. They were of the 20Cr – 10Ni type with and without niobium. The test specimens used had the details shown at the top of Fig. 34. The notched specimens provided a stress concentration factor of 3.0 at the root of the notch.

From the upper graph, Fig. 34, the ratio of the average unit nominal ultimate strength of the notched to the unnotched as-deposited weld metals was always greater than unity, that is, by definition these metals were not notch sensitive.[11] As the test temperature increased from −300° F the ratio of strengths for both compositions increased, the relative changes being about the same at all temperatures, and particularly between 0 and 1800° F.

Almost all of the strain in the notched specimens was confined to the very short length within the width of the notch. For the type 347 metal, wherein the unnotched 1800° F test temperature strain at rupture was only 5.7%, little total strain was possible before rupture in the notched condition. The ratio of the magnitude of that strain in the

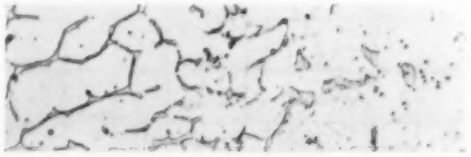
1.5-in. gauge length to the amount in the unnotched specimen was 0.06, between 1400 and 1800° F. At 1800° F the notched type 347 specimen failed at only 0.004-in. over-all elongation on the 1.5-in. gauge length. These facts re-emphasize the importance of having some available plastic flow at high temperatures in the making of Cr-Ni steel welds under restrained conditions. The type 308 weld without niobium, having a 20% and higher strain capacity in the unnotched condition, could flow locally under the notched condition and, while its total notched strain necessarily remained relatively low because of geometry, this capacity to flow was less dependent upon temperature than the niobium-bearing weld, lower graph, Fig. 34.

Solution Heat Treatment

Solution heat treatment achieves two objectives for the alloyed welds, such as those containing higher niobium, (see Figure 12). It returns the carbides, and possibly other compounds, into solution in the austenitic matrix, and results in a rearrangement of the dendritic and irregular ferrite particles into more nearly spherical forms, upper insert of Fig. 35. These features tend to reduce the 80° F yield strength by more than half while only slightly reducing the ultimate stress and conversely increasing the fracture stress. All the indexes of ductility, reduction of area, total elongation and uniform elongation are substantially increased by a suitably high-temperature treatment, Fig. 35. Similar but proportionately far greater improvements are effected at the higher test temperatures, such as 1650° F, Fig. 36. These improvements cannot be achieved without first raising the weld through the 1800° F temperature of the brittle zone, Fig. 12. A massive weldment inherently has high residual shrinkage stresses, Fig. 2, of the order of the yield strength of the base metal. The yield stress of the base metal is less than that of the weld metal at and near ambient temperature, which is a factor in heat-affected zone cracking. In heat treatment, as the volumetric units of the weldment pass through the brittle temperature zone under differential stresses, strains of sufficient magnitude can be induced to cause local rupture of the brittle weld metal or in the heat-affected zone of the base metal since the normal as-produced plate metal has adequate ductility at most temperatures.[12, 13] This could readily explain the phenomenon of shop-cracking experiences during heat treatment even for sound weldments with no prior microfissuring. Of course, the compositions, brittle at 1800° F when welded under high orders of restraint with sharp notches, are most likely to contain initial fissures. The sum of the two phenomena has been known to produce gross production cracking during heat treatment.

This action in welds originally free of microfissures was illustrated in the laboratory by making longitudinal tensile specimens having axes on the bond line between the weld and the plate and having a gradually tapered section so that high stresses and strains would occur in the minimum section and low values of both would exist in the gross section. Such specimens were pulled to rupture at 1500 and 1800° F. A longitudinal section after rupture shows that fracture occurred at the location of maximum stress and strain, that is, at the minimum area. Fissuring existed *only* near the regions of highest stress and strain. With this technique it is possible to develop, in a single specimen, the stress-strain conditions at rupture and the minima required to produce fissuring at any particular temperature level.

The fact that a given composition of weld metal may have a poor or high order of ductility at elevated temperatures is only another example of the fact that physical properties are as dependent upon structure arrangement as upon composition. For these reasons it is important to know the temperature-ductility characteristics of the weld metal prior to specification



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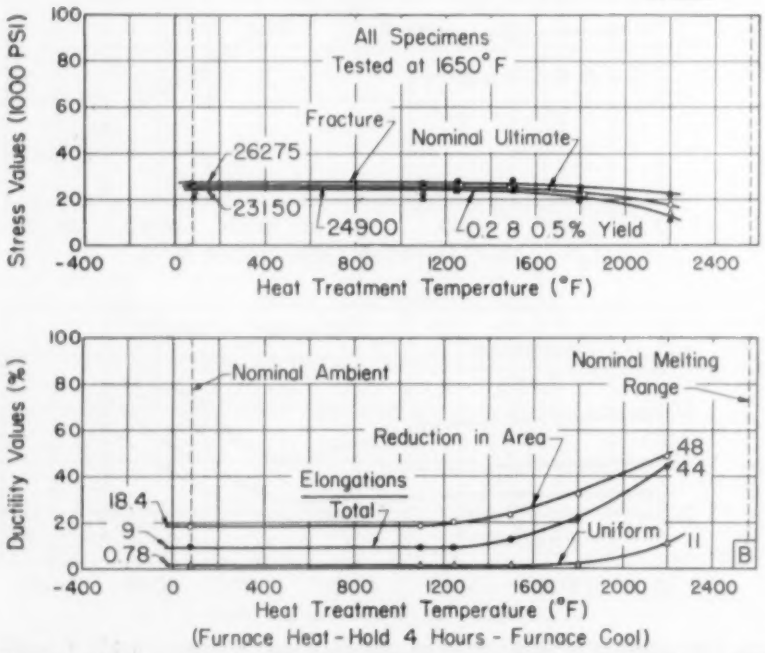

Fig. 36 Influence of heat treatment upon short-time tension properties of type 347 covered electrode weld metal at 1650° F

of heat treatments. Local stress rupturing must be avoided.

Delayed Cracking

The fourth condition of commercially observed cracking is that which sometimes occurs in service at modest operating temperatures. The data just described, when coordinated with already published creep data, tend to aid in an explanation of this phenomenon. It is known that at the higher temperatures under stressed conditions both strength and ductility of metals tend to decrease from their initial values.[2] Therefore, by using time as a third dimension in the strength-temperature and ductility-temperature plots, such as shown in Figs. 3–16, one should expect early failure at 1800° F for the welds having very low short-time elongations at 1800° F. If parallel creep or stress rupture tests were made at progressively decreasing temperatures on welds where only 6% strain was available initially in a 0.48-min. life test at 750% per hour, one would expect to find that gradually increasing times were required before the ductility and fracture stress curves reached down to such low levels that they were below those which are representative of service stress and strain requirements and which could thus cause rupture. As temperatures were further reduced to the point coincident with the sharp dip in the ductility and fracture stress vs. temperature curves, as in Fig. 12, one would expect a change of slope in the stress rupture curves. This is exactly what was found.[14] More precise experimental verification of this relationship has been undertaken and if substantiated will serve to re-emphasize the desirability for the deposition and use of weld metals free of low ductility dips at the higher temperatures.

Summary

The controlled temperature, constant strain rate, unnotched tensile test was found to be very useful in the study of high-temperature brittleness of weld metals which may, under adverse conditions, lead to microfissuring, cracking or even rupturing. Such tests are much more useful than the commonly used "weldability" tests wherein welds are made under various but undefinable orders of restraint and are later examined only for the presence or absence of cracks.[3]

The low orders of hot ductility, when found, were usually centered around the temperature of 1800° F. Cracking related to these metals, therefore, does not necessarily occur only at the moment of freezing of the melt.[10]

High-temperature brittleness may be present in welds having microstructures which are austenitic at room temperature as well as those which contain varying amounts of ferrite or other phases at room temperatures, that is, welds may be either ductile or brittle at high temperatures regardless of the room-temperature ferrite content, Figs. 20 and 21. There is, therefore, no single specific relation between as-deposited room-temperature ferrite content and hot ductility as commonly believed.[8] Welds which are fully austenitic at room temperature, however, cannot be ductile at high temperatures unless microscopically clean grain boundaries exist. Precise dimensional definitions of cleanliness in terms of microconstituents are not possible at this time, but composition trends as they affect ductility are believed to be qualitative measure as indicated in Fig. 28.

The 1800° F brittleness is shown to be related to the strength of the matrix at that temperature. The higher strength matrixes impose higher stresses on the grain and subgrain boundaries and barriers and upon the local particles. Unless these are sufficiently strong at the high temperatures, failure may occur under low orders of strain. Hot brittleness, or lack of ductility, is therefore a function of the composition components which strengthen the matrix as well as of those which weaken the grain or subgrain boundaries.[1]

In the commercial Cr-Ni steel weld metals, nickel and niobium provide the major sources of high-temperature matrix strength with chromium additions tending to lower that strength. Grain boundary weakening is shown to be related to the presence of oxides, nitrides, carbides and silicates at the grain, subgrain and particle boundaries even when the sulfur and phosphorus contents are low.

Better high-temperature ductility is secured for a given strength level when alloying additions of manganese, titanium, molybdenum and tungsten are added with lowered nickel contents, Figs. 25 and 26. A similar effect is secured from the use of niobium. However, niobium is such an effective strengthener that, for rapidly quenched conditions, welds containing this element tend to become over-strong and under-ductile at high temperatures, that is, over 1500° F. This is particularly true when electrodes comply with the presently effective commercial specification limits which require a minimum niobium of eight times the carbon content with a 1% niobium maximum.[15]

Solution heat treatment is effective in improving high-temperature ductility of type 347 niobium-bearing welds but to achieve this improvement it is necessary to heat the weld through the region of minimum ductility. Complex or rigid parts may crack upon heating while undergoing this transition unless properly handled. After holding at a sufficiently high temperature adequate ductility is available for the final cool-down.

Welds having low capacity to strain at high temperatures in the unnotched condition are particularly strain sensitive in the notched condition wherein the strain is concentrated at the root of the notch. In high-temperature strain-sensitive metals, such sharp notches should be avoided both during the deposition of the weld and in the product design.

Commercial practices often involve the use of welds which are over-strong and under-ductile, particularly at the higher temperatures. Wire and coating compositions and arc-shielding techniques should conform to the limits required to provide welds having adequate high-temperature ductility. This can be done by

holding the silicon, carbon, nitrogen and oxygen to suitable minima and by avoiding excessive additions of nickel and niobium. Likewise, excesses of chromium should be avoided so that the formation of the brittle sigma phase may be minimized. Specific limits will depend upon specific conditions. The data presented clearly indicate the probability that in the early future improved welding electrodes and procedures will be available which will minimize or eliminate cracking in properly designed and fabricated structures of these metals. Test data, not included in detail, show that excellent results are also secured with 4% Mn, 0.90% Mo type compositions.

The welds having low ductility at 1800° F in these tests had a high product of strength and grain boundary contaminant factors, Fig. 28. All such weld compositions, which include types 310, 330, 347 and 310 Si, have been directly observed to experience varying degrees of service cracking. Such cracking has also been reported in the literature.[6,7,10,16—20]

Present practice is to evaluate welding electrodes for deposit properties at room temperature.[15] A more suitable approach, for massive rigid applications, would be to evaluate deposit properties and electrode and technique suitability on the basis of performance within the 1500 to 2200° F temperature range.

Acknowledgments

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*Materials Engineering.

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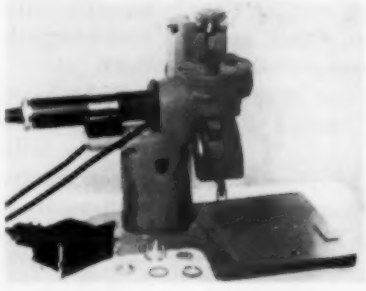
RESEARCH NEWS

Three-Specimen Spectrograph

A new Norelco Three-Specimen Inverted Spectrograph, designed so the X-ray beam strikes specimens from the bottom, for analysis of metals, powders and liquids such as heavy waxes and oils, has been announced by the Research and Control Instruments Division, North American Philips Co., Inc., 750 South Fulton Ave., Mount Vernon, N. Y.

The instrument has three specimen holders measuring $1^3/_8$ in. diameter by $1^3/_8$ in. deep which fit into a horizontal disk that rotates inside a leaded-bronze rayproof housing. The disk shaft extends through the top of the housing and has a knob which the operator turns manually when he wishes to change specimen positions. An indexing device centers each specimen when over the beam and shows whether it is No. 1, 2 or 3.



Specimen holders have $^1/_4$ mil thick mylar windows held in place with retaining rings to facilitate replacement. A nickel foil collimator with $^1/_8$-in. spacing is built into the instrument.

Special accessories are available for use with the instrument. One attachment provides a synchronous motor for rotating the specimen approximately 78 rpm. Another attachment makes it possible to employ a helium atmosphere. Still another allows specimens to be heated while in the chamber.

Additional information may be had by writing directly to the company at above address.

EFFECTS OF INTERSTITIAL ELEMENTS ON WELDABILITY OF TITANIUM ALLOY SHEET—PART 2

Three interstitial elements, carbon, nitrogen and oxygen, have been found to impair the weldability of titanium alloy sheet under some conditions

BY H. M. MEYER

ABSTRACT. Three interstitial elements, carbon, nitrogen and oxygen, impair the weldability of titanium alloy sheet. To quantitatively evaluate their effects, three typical base alloys containing small, intentional additions were welded. The alloys were:

A binary α alloy: 5% Al–Ti.

A ternary alloy containing an α and a β strengthening element: 7% Al–3% Mo–Ti.

A binary β alloy: 25% V–Ti.

Weldability was to be determined essentially by bend ductility, while other mechanical properties of pilot and weldment were also investigated. Typical pre- and postheat treatment cycles were to be selected for each individual alloy and interstitial addition to establish trends for restoring ductility, or strength, or a combination of both.

In the introductory Section I, methods of preparation, treatment and testing of the alloy sheet are described. Sections II, III and IV report on the mechanical properties of weldments in the three base alloys.*

H. M. Meyer was Research Metallurgist, Metals Research Department, Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill., where this study was carried out, and is now Chief, Metals Research Branch, Watertown Arsenal Laboratory, Watertown, Mass.

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* Sections I and II formed Part 1 which was published in the August, 1955 issue of the *Welding Research Supplement*. Sections III and IV constitute Part 2. This abstract covers complete study.

Table 6—Heat-Treating Cycles for 7Al – 3Mo–Ti Weldments

No.	*Condition*	*Order of sequence*	*Heat treatment*
1	Pilot	...	Stress relief 30 min at 800° F
1W	Weld	Pre	Stress relief 30 min at 800° F
2	Pilot	...	1600° F—15 min → WQ
2W	Weld	Post	1600° F—15 min → WQ
3	Pilot	...	1600° F—8 hr → WQ
3W	Weld	Post	1600° F—8 hr → WQ
4	Pilot	...	1025° F—30 min → WQ
4W	Weld	Post	1025° F—30 min → WQ
5	Pilot	...	1025° F—16 hr → WQ
5W	Weld	Post	1025° F—16 hr → WQ
6	Pilot	...	1600° F—15 min → 1025° F—30 min → WQ
6W	Weld	Post	1600° F—15 min → 1025° F—30 min → WQ
7	Pilot	...	1600° F—8 hr → 1025° F—16 hr → WQ
7W	Weld	Post	1600° F—8 hr → 1025° F—16 hr → WQ
8	Pilot	...	1600° F—8 hr → WQ—1025° F—16 hr → WQ
8W	Weld	Post	1600° F—8 hr → WQ—1025° F—16 hr → WQ
9	Pilot	...	2050° F—15 min → 1025° F—16 hr → WQ
9W	Weld	Post	2050° F—15 min → 1025° F—16 hr → WQ
10W	Weld	Pre	1025° F → 16 hr → WQ

Limits of addition in 5Al–Ti proved to be 0.20% for carbon, 0.18% for nitrogen and 0.25% for oxygen. No general pattern emerged for 7Al – 3Mo–Ti; 0.15% O_2 yields strong, ductile microstructures in the postannealed weld zones. The 25V–Ti alloy showed little effect from carbon additions. Nitrogen produced erratic ductility results; oxygen bearing as-welded sheet was strong and ductile.

Side developments were the production of workable, weldable 8Al–Ti. Also 15V–Ti displayed an unorthodox, but promising response to low-temperature isothermal anneals.

Microstructures were methodically used

Table 7—Actual Composition of the 7Al – 3Mo – Ti Base Sheet

Test No.	*Heat No.*	*Nominal composition*	*Chemical analysis, wt-%* Al	Mo	C	N	O_2	H_2
4394–4412	7730	7Al – 3Mo	6.75	3.10	(0.04)*	(0.02)	(0.09)	(0.016)
4413–4431	7621	7Al – 3Mo – 0.075C	6.63	3.38	0.0755	...	0.068	0.0084
4432–4450	7731	7Al – 3Mo – 0.15C	6.92	2.96	0.15	...	...	...
4451–4469	7640	7Al – 3Mo – 0.2C	6.83	3.30	0.19	...	...	...
4470–4488	7643	7Al – 3Mo – 0.075N	7.04	3.49	...	0.097	...	...
4489–4507	7644	7Al – 3Mo – 0.15N	6.88	3.32	...	0.174	...	...
4508–4526	7635	7Al – 3Mo – 0.2N	7.00	3.40	...	0.236	...	...
4527–4545	7634	7Al – 3Mo – 0.075O_2	6.91	3.44	...	...	0.152	0.021
4546–4564	7638	7Al – 3Mo – 0.15O_2	6.90	3.36	...	...	0.260	0.019
4565–4583	7727	7Al – 3Mo – 0.2O_2	7.08	2.96	...	...	0.338	0.036

* The contents listed in parentheses refer to interstitials present in the titanium sheet without any additions and constitute the average of a number of analyses.

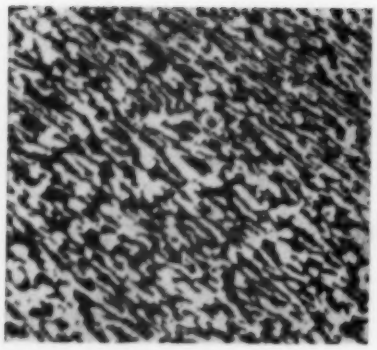

Fig. 43 Base metal 7Al – 3Mo–Ti, as-stress relieved. UTS 167,000 psi; folding distance $2^{11}/_{16}$ in.; elongation 2%. × 750

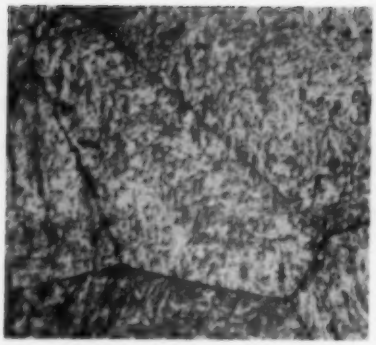

Fig. 44 Weld metal 7Al – 3Mo–Ti, as-welded. (Same specimens as Fig. 43.) × 500

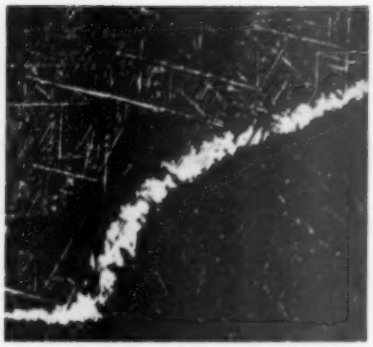

Fig. 45 Weld metal 7Al – 3Mo–Ti, annealed 8 hr at 1600° and 16 hr at 1025° F. UTS 159,900 psi; folding distance $^3/_4$ in.; elongation 5%. × 500

to explain the mechanical properties of the welded zones, and several microstructural phenomena were uncovered.

Hardness was not a satisfactory indicator of brittleness in weld zones; it was, however, of good use for controlling the contamination of α alloy.

Interstitial elements in titanium alloy sheet weldments are harmful; where possible, limits of usefulness have been described. The fundamental study should help to enlarge and clarify the range of weldable titanium-alloy compositions. Heat treatments that will restore ductility after embrittlement by the welding cycle are described in terms of individual phase relationships.

PART 2

III. 7% Aluminum – 3% Molybdenum – Titanium Alloy

Advantages of aluminum as an α titanium strengthener are limited above 7% by the problem of workability. Since interstitial solubility in α titanium exceeds the β solubility the question is whether presence of a β-strengthening element, like molybdenum, in the borderline 7% Al composition will alleviate the weld embrittlement by interstitials. Therefore, 3% Mo was alloyed with 7% Al–Ti; then C, N_2 and O_2 were added, but in amounts smaller than those added to 5Al–Ti. The added interstitial amounts were 0.075, 0.15 and 0.2%.

Table 8—Mechanical Properties of 7Al – 3Mo Sheet

			Free-bend test							*Tensile test*		
			Transverse		*Longitudinal*	*Guided-bend test*						
No.	*Condition**	*Postheat treatment*	*Folding distance, in.*	*Failure†*	*Folding distance, in.*	*Transverse diam*		*Longitudinal diam*		*Ultimate tensile strength, psi*	*Elongation in 2 in., %*	*Failure†*
						In.	*Angle*	*In.*	*Angle*			
1	Pilot	None	$^1/_8$	...	...	$^1/_2$	35	..	..	172,000	4	
	Weld	None	$2^{11}/_{16}$	HAZ	$1^7/_8$	$^1/_2$	28	$^1/_2$	25	167,000	2	WM
2	Pilot	1600° F/15 min → WQ	$^5/_8$	...	...	$^1/_2$	38	..	..	155,000	7	
	Weld	1600° F/15 min → WQ	$^{15}/_{16}$	HAZ	$1^3/_4$	$^1/_2$	33	$^1/_2$	30	144,000	7	BM
3	Pilot	1600° F/8 hr → WQ	$^7/_8$	...	...	$^1/_2$	35	..	..	141,000	0	
	Weld	1600° F/8 hr → WQ	$1^5/_8$	WM	$1^7/_8$	$^1/_2$	65	$^1/_2$	30	138,200	7	WM/HAZ
4	Pilot	1025° F/30 min → WQ	$^{13}/_{16}$	...	...	$^1/_2$	30	..	..	168,200	4	
	Weld	1025° F/30 min → WQ	3	WM	$1^{13}/_{16}$	$^1/_2$	28	$^1/_2$	15	167,500	3	BM
5	Pilot	1025° F/16 hr → WQ	$^5/_8$	...	...	$^1/_2$	35	..	..	184,700	6	
	Weld	1025° F/16 hr → WQ	$3^{11}/_{16}$	WM	$1^7/_8$	$^1/_2$	38	$^1/_2$	23	174,800	2	WM
6	Pilot	1600° F/15 min → 1025° F/30 min → WQ	0	...	...	$^1/_4$	45	..	..	162,500	8	
	Weld	1600° F/15 min → 1025° F/30 min → WQ	$1^7/_8$	HA	$1^3/_4$	$^1/_2$	35	$^1/_2$	25	151,500	5	WM
7	Pilot	1600° F/8 hr → 1025° F/16 hr → WQ	$3^3/_8$	...	...	$^1/_2$	78	..	..	156,000	9	
	Weld	1600° F/8 hr → 1025° F/16 hr → WQ	$4^1/_2$	WM	2	$^1/_2$	35	$^1/_2$	25	162,200	5	WM
8	Pilot	1600° F/8 hr → 1025° F/16 hr → WQ	$1^5/_8$	...	...	$^1/_4$	55	..	..	167,700	9	
	Weld	1600° F/8 hr → 1025° F/16 hr → WQ	$^3/_8$	BM	$1^7/_8$	$^1/_2$	35	$^1/_2$	33	159,900	5	WM
9	Pilot	2050° F/15 min → 1025° F/16 hr → WQ	$3^3/_{16}$	...	...	$^1/_4$	40	..	..	163,200	1	
	Weld	2050° F/15 min → 1025° F/16 hr → WQ	$1^5/_{16}$	WM/HAZ	$1^7/_8$	$^1/_4$	30	$^1/_4$	38	174,400	3	WM
10	Weld	Preheat—1025° F/16 hr → WQ	$4^7/_{16}$	WM	$1^7/_8$	$^1/_2$	25	$^1/_2$	20	124,000	1	WM

* Stress relieved 30 min at 800° F.
† WM: Weld metal. HAZ: Heat-affected zone. BM: Base metal.

Table 9—Vickers Hardness of Welded 7Al – 3Mo – C – Ti Sheet

No.	Heat No.	Postheat treatment	Vickers hardness Nos. 0.075 C BM	0.075 C WM	0.15 C BM	0.15 C WM	0.19 C BM	0.19 C WM
1	7621 7731	As-welded	379	417	388	412	406	419
2	7640	1600° F/15 min → WQ	346	377	379	404	360	367
3		1600° F/8 hr → WQ	351	384	351	402	376	400
4		1025° F/30 min → WQ	412	477	425	435	431	436
5		1025° F/16 hr → WQ	414	449	405	449	422	441
6		1600° F/15 min → 1025° F/30 min → WQ	397	420	383	421	396	429
7		1600° F/8 hr → 1025° F/16 hr → WQ	394	424	380	425	409	419
8		1600° F/8 hr → WQ → 1025° F/16 hr → WQ	372	407	399	405	404	427
9		2050° F/15 min → 1025° F/16 hr → WQ	428	443	411	411	415	415
10		Preheat 1025° F/16 hr → WQ	374	417	410	427	425	443

The $\beta/\alpha + \beta$ phase boundary is at 1920° F (see Fig. 2*); it is known that the retained β phase is not stable, that $(\alpha + \beta)$ heat treatments produce a Widmanstatten α skeleton in the structure and that subsequent low-temperature anneals add strength.[4] With this information available the heat treatment cycles were selected (see Table 6). As the two $(\alpha + \beta)$ temperatures 1600 and 1025° F were determined as typical for high- and low-temperature isothermal anneal. Short and long annealing times were to be 15 min and 8 hr at the high temperature, and 30 min and 16 hr at the low temperature. Beside the simple reheat type treatment (Nos. 2 to 5), double isothermal type anneals (Nos. 6 and 7) and quench-and-reheat type treatments (No. 8) were applied. Also, one step-quench type anneal (No. 9) and a simple preheat treatment† (No. 10) were added to the tests.

Nominal and analyzed compositions of the 10 alloys are given in Table 7. No hardness readings were taken during the preparatory operations as had been in the case of 5Al-Ti since their correlation with contamination is impossible with α and β phase present simultaneously. However, hardness traverses of all weldments were run to study whether any relation to zone brittleness might exist.

(1) 7 Aluminum – 3Molybdenum – Titanium Without Additions

Rolled, stress-relieved sheet has a duplex $\alpha + \beta$ structure, and the as-welded weld metal consists of coarse β grains with acicular α. Long $\alpha + \beta$

* Figures 1 through 425 have been published in Part 1.

† Preheat treatment is a heat treatment applied prior to the welding operation.

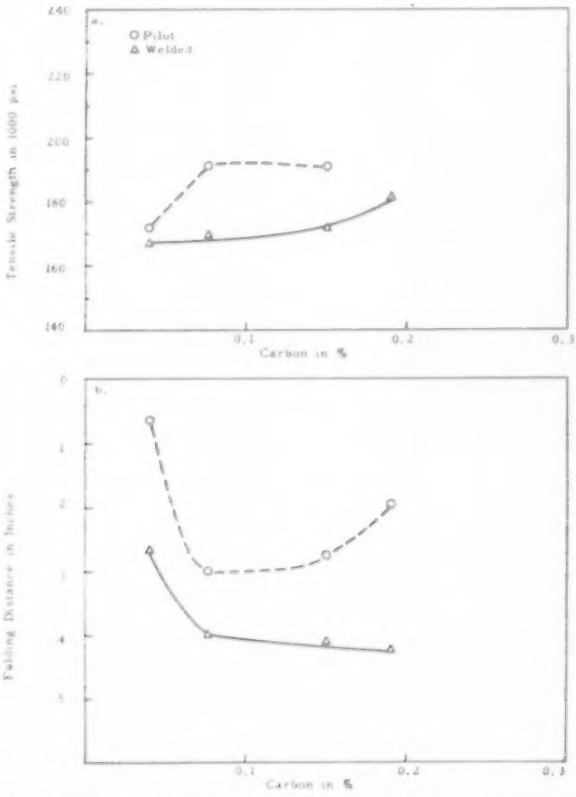

Fig. 46a and b Mechanical properties of weldments vs. C addition. 7Al – 3Mo–C–Ti sheet; as-welded

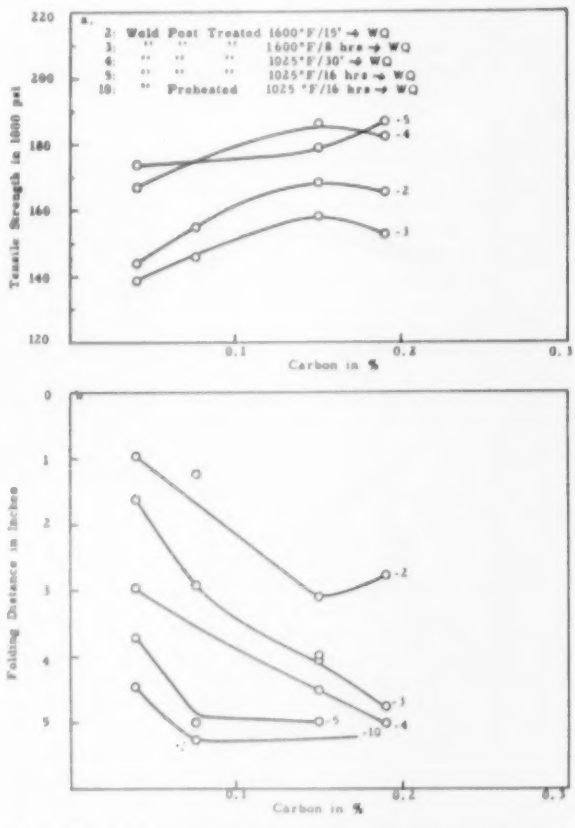
a.
2: Weld Post Treated 1600°F/15' → WQ
3: " " " 1600°F/8 hrs → WQ
4: " " " 1025°F/30' → WQ
5: " " " 1025°F/16 hrs → WQ
10: " Preheated 1025 °F/16 hrs → WQ
Tensile Strength in 1000 psi
Carbon in %
Folding Distance in Inches
Carbon in %

Fig. 47a and b Mechanical properties of weldments vs. C addition. 7Al – 3Mo–C–Ti sheet; pre- and postreated

anneals widen and disrupt the former β grain boundaries and reinforce the acicular microstructures which is ductile. Figures 43 to 45 present three typical structures. The pilot sheet, stress relieved at 800° F, is strong and bend ductile although its tensile elongation is only 4% (see Table 8, first line). Welding embrittles without much loss in strength. Short time anneal at high (α + β) temperature (No. 2) reduces brittleness and strength, but long anneal (No. 3) does not achieve ductility.

Low-temperature (α + β) anneals, whether short or long, embrittle the weld (Nos. 4 and 5) while the 16-hr annealed pilot sheet attains 184,700 psi without loss of ductility. The best pilot ductility is produced by double anneal (No. 6); however, strength is lower, as it is also in the weldment which has insufficient ductility. The longer anneal (No. 7) does not yet develop the structure where the fine α precipitate has been rendered inoffensive. After 16 hr at 1025° F, both pilot and weldment fold only to over 3 in., although some tensile elongation (3 and 5%) still exists.

The quench-and-reheat type cycle improves mechanical properties (No. 8, compare Fig. 45). Step-quench β treatment (No. 9) does not hold much promise, while preheat treatment makes the weld weak and brittle (No. 10) but the pilot strong and ductile (No. 5). The only anneal removing weld-brittleness without excessive loss in strength is the No. 8 quench-and-reheat type treatment.

The longitudinal free-bend and the two guided-bend test methods lack sensitivity with the 7Al–3Mo–Ti alloys. Hardness values are in general slightly higher in the weld metal than in the base metal; the average Vhn's of both zones are listed in Table 9. The low-temperature anneal produces the highest hardness while the high-temperature (α + β) treatment hardens the weld metal much less. The weld metal hardness after the mechanically desirable cycle No. 8 attains 379 Vhn without any embrittlement.

(2) 7Aluminum – 3Molybdenum – Titanium with Carbon Addition

Carbide does not dominate structures as it did in the 5Al–C–Ti alloys; however, small carbide particles form in subgrain boundaries when over 0.15% C are present. Carbon limits the size of the transformed particles in low-carbon alloys.

Carbon strengthening of the pilot is substantial but moderate in the weldment as shown in the two curves of Fig. 46*a*. High-temperature anneal reduces the strengthening effect but low temperature anneal increases it (see Fig. 47*a*). Double isothermal type or quench-and-reheat type posttreatments do not make carbon a better strengthener (Fig. 48*a*).

Carbon embrittles, but the effect does not increase with higher additions. The sheet is brittle in the as-welded state (Fig. 46*b*). Postanneal at high temperature reduces brittleness of low alloys, but is ineffective at low temperature (Fig. 47*b*). Double isothermal type or quench-and-reheat type anneals produce ductile welds in 0.076 C alloy only (Fig. 48*b*).

Even when the hardness traverse shows no hardening of the weld metal, it is brittle; on the other hand, reasonable bend ductility of low-carbon weldments is accompanied by softness after the short low-temperature treatment.

(3) 7Aluminum – 3Molybdenum – Titanium with Nitrogen Addition

Nitrogen does not affect microstructures of the weld zones to a substantial degree. The as-welded weld metal with acicular α in coarse β grains resembles Fig. 44; the densely serrated acicular α in equiaxed β grains of the annealed weld metal is not significantly different from the N-free structure.

Nitrogen strengthening is high, as the

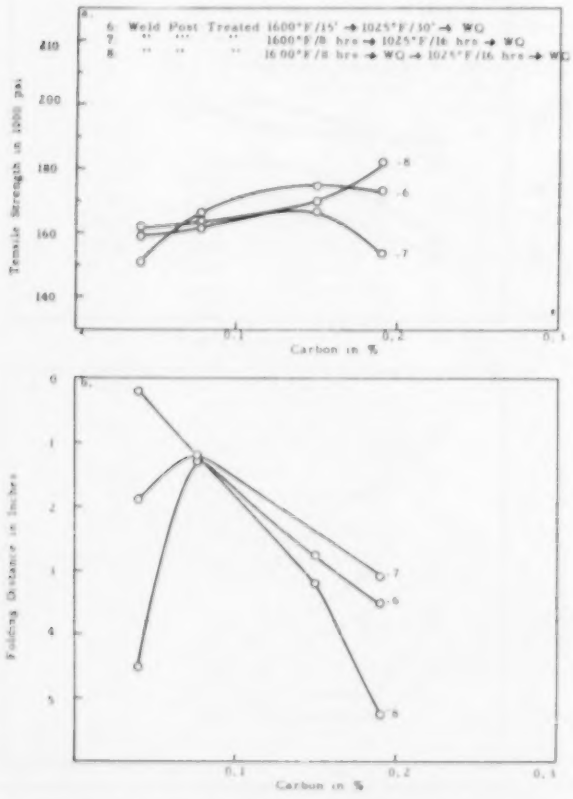
6 Weld Post Treated 1600°F/15' → 1025°F/10' → WQ
7 " " " " 1600°F/8 hrs → 1025°F/16 hrs → WQ
8 " " " " 1600°F/8 hrs → WQ → 1025°F/16 hrs → WQ
Tensile Strength in 1000 psi
Carbon in %
Folding Distance in Inches

Fig. 48*a* and *b* Mechanical properties of weldments vs. C addition. 7Al – 3Mo–C–Ti sheet; posttreated

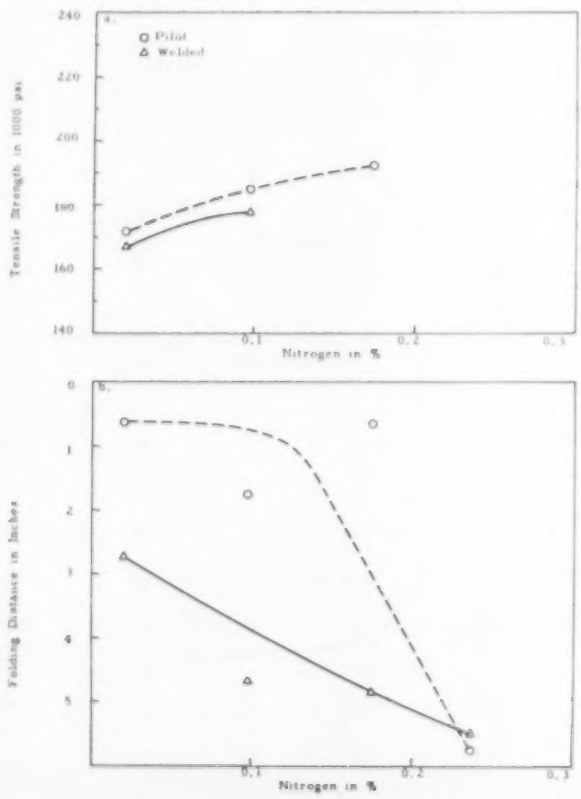

Fig. 49*a* and *b* Mechanical properties of weldments vs. N addition. 7Al – 3Mo–N–Ti sheet; as-welded

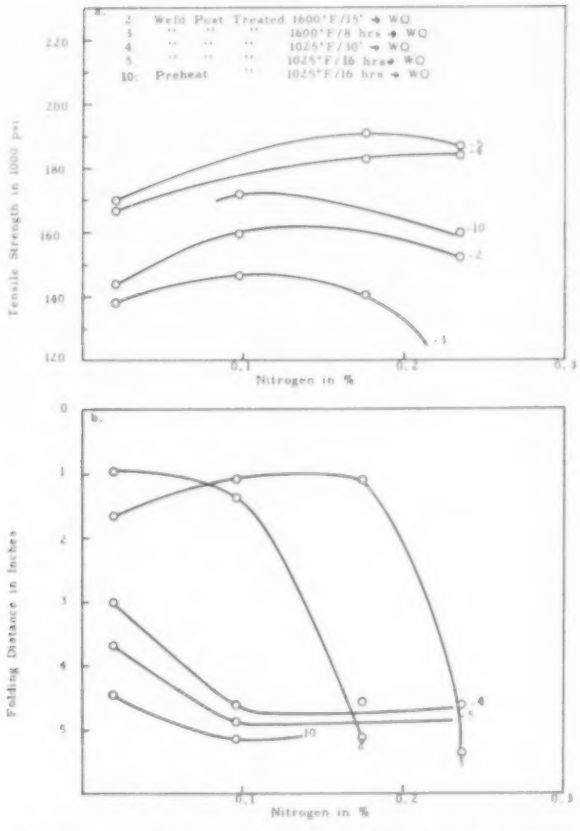

Fig. 50*a* and *b* Mechanical properties of weldments vs. N addition. 7Al – 3Mo–N–Ti sheet; pre- and post treated

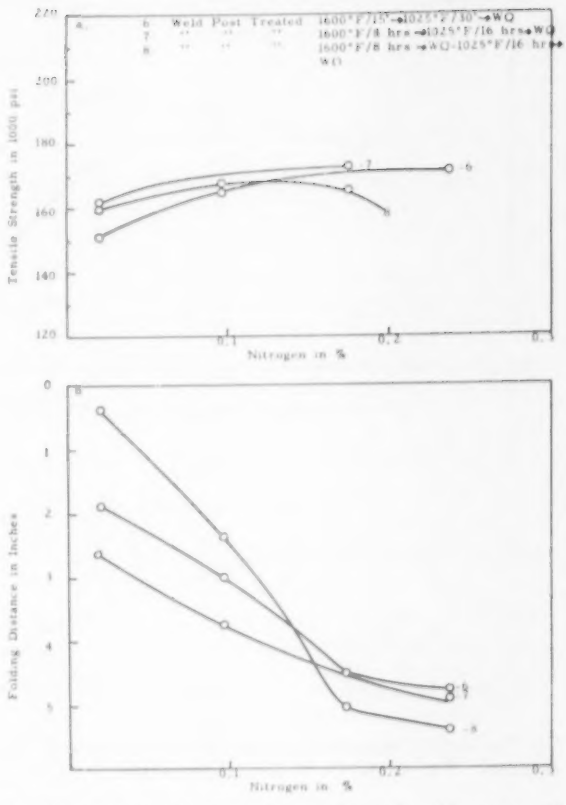
Weld Post Treated 1600°F/15' →1025°F/30' →WQ
1600°F/8 hrs →1025°F/16 hrs →WQ
1600°F/8 hrs →WQ-1025°F/16 hrs →WQ
Tensile Strength in 1000 psi
Nitrogen in %
Folding Distance in Inches

Fig. 51*a* and *b* Mechanical properties of weldments vs. N addition. 7Al – 3Mo–N–Ti sheet. Post treated

curves of Fig. 49*a* demonstrate. Post-anneal at high temperature reduces the welded strength at 0.1% N to 160,000 psi and raises it at 0.17% N to 192,000 at low temperature (Fig. 50*a*). Double isothermal type or quench-and-reheat type anneals result in strength values which are similar to the as-welded, N-free base alloy (Fig. 51*a*).

Pilot sheet is embrittled by 0.2% N, i.e., by the same addition which embrittles 5Al–Ti; but the welded 7Al-3Mo–Ti is brittle without any addition and grows even more so when N is present (Fig. 49*b*). Posttreatment at high temperature improves weldability of the medium alloy but destroys it at lower temperature (Fig. 50*b*). After double isothermal type or quench-and-reheat type treatments the weldability deteriorates with higher additions (Fig. 51*b*).

The hardness traverses in weld metal and base metal reach the highest level of all alloys tested and attain the 500 Vhn level in the weld metal after 16 hr at 1025° F.

(4) 7Aluminum – 3Molybdenum – Titanium with Oxygen Addition

Step-quench type treatment produces good weldable structures (Fig. 52);

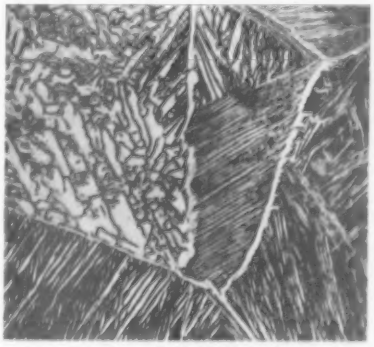

Fig. 52 Weld metal 7Al – 3Mo–0.15O_T–Ti, annealed 15 min at 2050° and 16 hr at 1025° F. UTS 139,600 psi; folding distance 7/8 in. elongation 4%. × 250

the difference between the weld zones has disappeared, β grain boundaries are in evidence and blocks of Widmanstatten plates develop into new grains.

The strengthening by oxygen is limited; over 0.26% causes premature failure (Fig. 53*a*). Postanneal at high temperature reduces the welded strength but also removes the cause of premature failure; low-temperature posttreatment raises the welded strength to 190,000 psi (Fig. 54*a*). Double isothermal type or quench-and-reheat type treatments do not add to the strength of the as-welded sheet, and produce premature failure in medium and high alloys (Fig. 55*a*).

The as-welded sheet is embrittled by small oxygen addition (Fig. 53*b*). High-temperature postanneals restore limited ductility except for the high O_7 alloy; they seem to hold some promise. Even low-temperature posttreatments, known for their invariably embrittling influence, are salutary to a degree (Fig. 54*b*). Double isothermal anneals are useful only when applied for short time to the low-oxygen alloy. The quench-and-reheat type cycle is ineffective (Fig. 55*b*) as is the preheat treatment.

Oxygen hardening is appreciable although not as much as the nitrogen effect, and is most noticeable in the low O_7 alloy. In this respect the influence differs from the experience with the 5Al–Ti base alloy. The high 460 Vhn value associated with weld ductility in low-oxygen weld metal after low-temperature isothermal postanneal is an exception to the previous results of weld embrittlement in titanium alloy welds with hardness exceeding 400 Vhn.

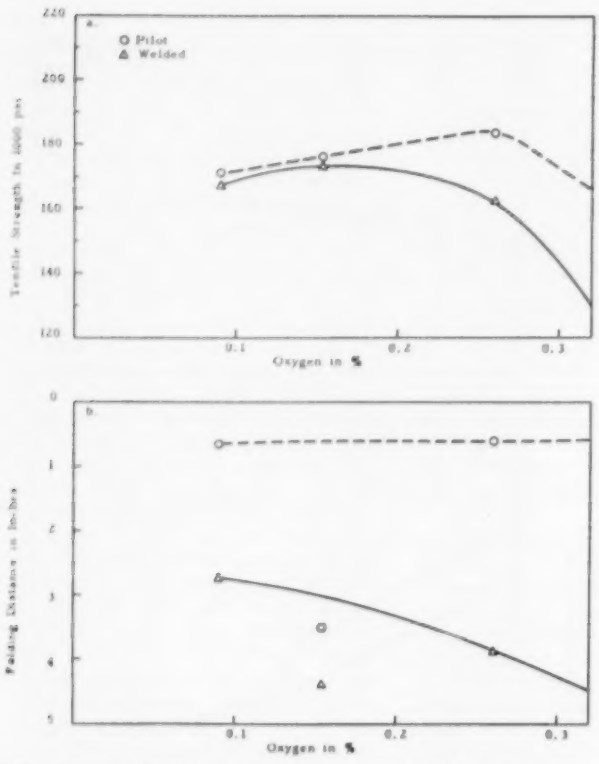

Fig. 53a and b Mechanical properties of weldments vs. O_2 addition. 7Al – 3Mo–O_2–Ti sheet; as-welded

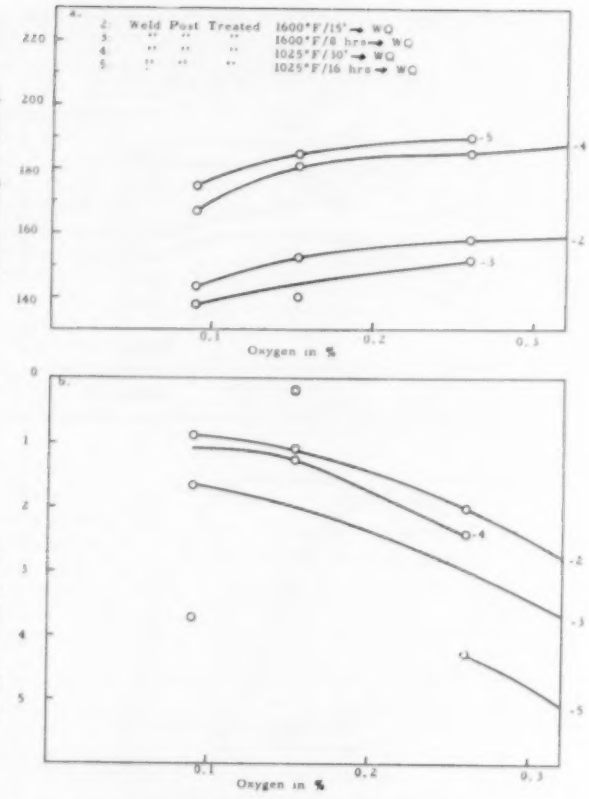
a.
2: Weld Post Treated 1600°F/15' → WQ
3: " " " 1600°F/8 hrs → WQ
4: " " " 1025°F/30' → WQ
5: " " " 1025°F/16 hrs → WQ
Tensile Strength in 1000 psi
Oxygen in %
b.
Folding Distance in Inches
Oxygen in %

Fig. 54a and b Mechanical properties of weldments vs. O_2 addition. 7Al – 3Mo–O_2–Ti sheet; posttreated

(5) Summary: Weldments in 7Al – 3Mo–Ti Alloy

Because binary 7Al–Ti is the highest α aluminum alloy which can be deformed without difficulty the question to be studied was: Will addition of a β stabilizing element alleviate weld embrittlement by interstitials? In a sense, the answer is yes: The long, low-temperature $\alpha + \beta$ anneal (No. 5) produces strong, ductile weldments in the 7Al–3Mo–0.15O_2–Ti alloy, its extreme weld metal hardness notwithstanding.

Structures in ternary 7Al – 3Mo–Ti are less revealing than in binary 5Al–Ti because of the presence of the ductile β constituent. Nonequilibrium structures are encountered in weld metal and heat-affected zone after heat treatments; α,α' and β phases of at least partly rather fine configuration occur. Their common feature is the broken-up former grain boundary which has grown into a wide band, frequently interspersed with α' needles. Carbon improves the structure by limiting the grain size; carbide precipitates when over 0.15% C is present. Nitrogen and oxygen do not alter the welded structure to any significant degree. β solution treatment produces blocks of serrated plates.

When welded, 7Al – 3Mo–Ti is strong and brittle. The Nos. 2 and 8 treatments produce ductile welds and a strength of 160,000 psi.

A carbon content of 0.19%, etc. raises the welded strength to 187,000 psi after No. 5 treatment; the pilot strength attains 211,000 psi (No. 4). Nos. 2 and 3 posttreatments ameliorate low-carbon weld brittleness.

Nitrogen is a potent strengthener; pilot strength is 217,000 psi and welded strength 191,000 psi after No. 5 treatment. But this advantage is overshadowed by weld embrittlement which causes premature tensile failures; the hardness attains 500 Vhn. Only the Nos. 2 and 3 posttreatments hold some promise.

Oxygen is a moderate strengthener and embrittles the as-welded sheet. Some anneals alleviate weld embrittlement; the best result was obtained in low O_2 alloy after No. 5 treatment with 181,000 psi and 1/8-in. folding distance.

High strength-ductility combinations among the results of this study are given in table at bottom of this page.

IV. Titanium-Vanadium System

Among the titanium base alloys to be studied was a metastable alloy, if one could be found. In the quest for this weldable alloy, compositions with 4, 8, 15, 25 and 30% vanadium were tested. The 15 and 25% alloys were subjected to heat treatment cycles similar to the ones employed for the analogous Ti-Mo system.[1] Interstitials were to be added later to the composition which would prove metastable. Is it possible to retain β after welding and heat treating? If so, what are the kinetics of the retained β when it undergoes subsequent anneals?

One serious difficulty with titanium alloys is that even when β is retained it frequently is in a brittle, so-called β', condition. Can brittle structures be avoided in the Ti-V weld zones?

Ultimate tensile strength, psi	*Folding distance, in.*	*Composition, wt-%*	*Postheat treatment*
150/160,000	3/4	7Al – 3Mo – Ti	1600° F/8 hr—WQ—1025°/16 hr
170/180,000	1/2	7Al – 3Mo – 0.15O_2–Ti	1600° F/15 min—1025°/30 min
180/190,000	1/4	7Al – 3Mo – 0.15O_2–Ti	1025° F/16 hr

(1) 15% Vanadium–Titanium Alloy

The analyzed vanadium content is between 14.99 and 15.3%. Rolling temperatures were from 1600 to 1650° F. Heat-treatment temperature was 1450° F in the β field (see arrow in Fig. 3) and isothermal anneals at 1200 and 1000° lasted 5 and 60 min. Both a step-quench and quench-and-reheat type treatment were applied.

The β phase in welded 15V–Ti is not stable. The as-welded and the pre-heat treated weldment are in the brittle β' condition. Hardness runs around 400 Vhn. Any postheat treatment results in precipitation of α in one of its forms and sizes. α' needles form in soft and ductile β grains of the weld metal. The needles are not stable and undergo a complex transformation to α and to β in a way similar to the needles in 5Al–O_2–Ti and Ti–Mo discussed in Figs. 35 and 38. The low-temperature isothermal anneal produces a uniformly dense and fine Widmanstatten precipitation in a relatively soft matrix of 290 Vhn.

Three heat-treatment types have been applied. The β treatment, alone and followed by aging at 1200 and 1000° F. The β treatment and the 1000° step-quench anneal as well as the 1000° quench-and-reheat type treatment result in ductile weldments. The tensile strength of the β treated weld of 117,000 psi increases to 130,000 psi after 1000° F anneal. The 1200° treatment is less effective. The good mechanical properties of the 15V–Ti step-quenched to the lower isothermal temperature are an interesting exception to the rule that

Table 10—Heat-Treatment Cycles Applied to 25% V–Ti Welds

Test No.	*Sheet condition*	*Heat treatment*	
		Sequence	*Kind*
1	Pilot Welded	...	None
2	Pilot Welded	Post	1400° F/15 min → 1000° F/5 min → WQ
3	Pilot Welded	Post	1400° F/15 min → 1000° F/90 min → WQ
4	Pilot Welded	Post	1400° F/15 min → 800° F/5 min → WQ
5	Pilot Welded	Post	1400° F/15 min → 800° F/120 min → WQ
6	Pilot Welded	Post	1400° F/15 min → WQ → 1000° F/90 min → WQ
7	Pilot Welded	Post	1400° F/15 min → WQ → 800° F/120 min → WQ
8	Pilot Welded	Post	1000° F/90 min → WQ
9	Pilot Welded	Post	800° F/120 min → WQ
10	Pilot Welded	Pre	1000° F/90 min → WQ

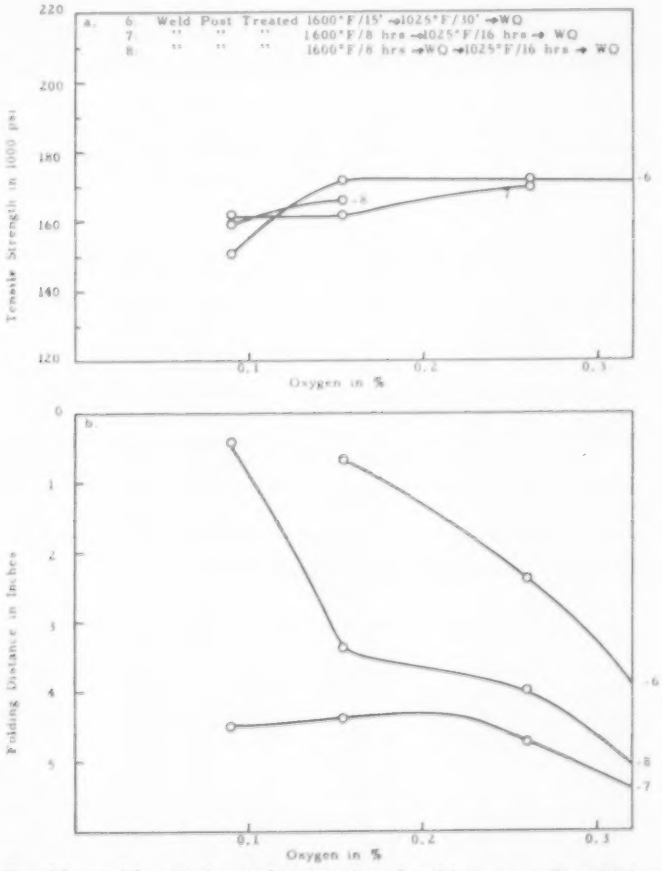
a. 6. Weld Post Treated 1600°F/15' →1025°F/10' →WQ
7. " " " 1600°F/8 hrs →1025°F/16 hrs → WQ
8. " " " 1600°F/8 hrs →WQ →1025°F/16 hrs → WQ
Tensile Strength in 1000 psi
Oxygen in %
b.
Folding Distance in Inches
Oxygen in %

Fig. 55a and b Mechanical properties of weldments vs. O_2 addition 7Al – 3Mo–O_2–Ti sheet; posttreated

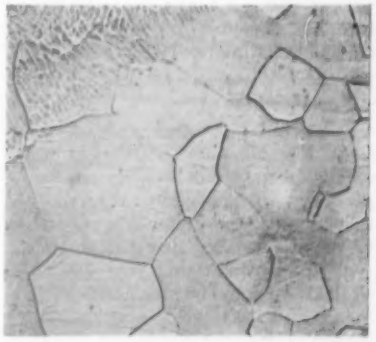

Fig. 56 Three weld zones (weld metal, cored, at upper left-hand corner), 25V–Ti. × 100

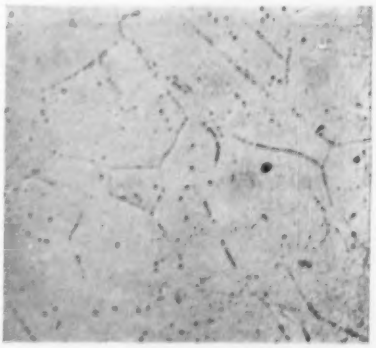

Fig. 57 Base metal 25V–Ti. (Same specimen as Fig. 56.) ×500

isothermal treatments embrittle more, the lower their temperature.

(2) 25% Vanadium–Titanium Alloy

A survey of the degree of β stability in the weld structures was conducted before the interstitial effect was studied. The heat-treat temperatures and cycles resemble those for the analogous 30% molybdenum–titanium[1] because their positions in the two-phase diagrams are the same, and it was thought that 25% V would be equivalent to 30% Mo in its ability to retain β phase. Therefore the heat treatments were to provide answers to the questions: (*a*) Will the cooling rate after treatment affect structures? (*b*) When the weldment is annealed will β phase be retained? Three $\alpha + \beta$ temperatures, 1050, 800 and 600° F, were applied.

The results indicate that pilot and weldment are in the soft, ductile β condition after solution treatment. Pretreatment reduces strength below the 100,000 psi mark.

The post β treatment grows more efficient with lower cooling rates; the strength of air and furnace cooled weldments rises to 124,000 psi, while hardness is low. Simple ($\alpha + \beta$) postanneal is not satisfactory because as strength increases, brittleness also develops and hardness, after 600° treatment, reaches 400 Vhn. The 25V–Ti conforms to the usual behavior pattern of embrittlement with decreasing temperatures and therefore was selected as the base alloy for interstitial additions.

(3) 25% Vanadium – Titanium without Additions

Solution temperature was raised to 1400° F to allow for the effect of interstitials on transition temperature (compare Fig. 3). In addition to the as-welded state, the weldments are tested in preheat treated and the following posttreated conditions: step quenched to 1000° for 5 and 90 min, and to 800° F for 5 and 120 min; quench-and-reheated to 1000° for 90 min and to 800° F for 120 min; simply reheated to 1000° for 90 min and to 800° F for 120 min (see Table 10).

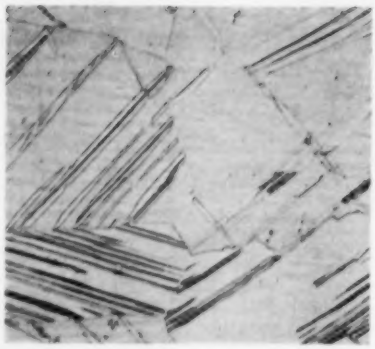

Fig. 58 Weld metal 25V–Ti, preheat treatment 15 min at 1400° F. UTS 95,000 psi; complete closure (0 in.). ×100

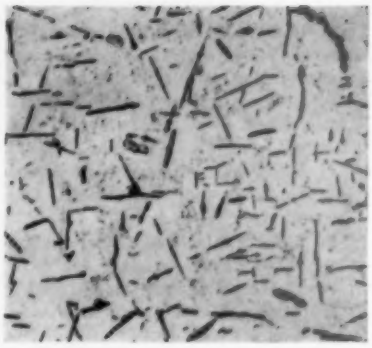

Fig. 60. Weld metal 25V – 0.23C–Ti. (Same specimen as Fig. 59.) UTS 97,250 psi; folding distance $^{7}/_{8}$ in.; elongation 3%. ×500

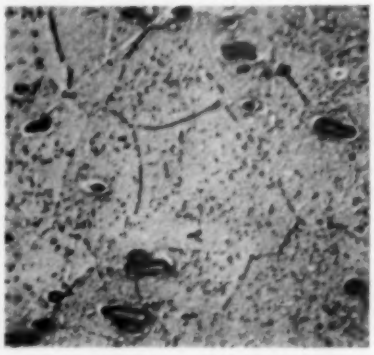

Fig. 59 Heat-affected zone 25V – 0.23C–Ti, annealed 15 min at 1400° —water quenched—annealed 2 hr at 800° F. ×500

Fig. 61 Weld metal 25V – 0.34C–Ti, annealed 90 min at 1000° F. UTS 103,300 psi; folding distance $4^{3}/_{8}$ in.; elongation 1%. ×500

Weld metal in the as-welded state consists of pure β phase (see Fig. 56); higher magnification, however, reveals fine grain and subgrain boundary precipitate (see Fig. 57). The presolution treated weld metal presents another instance of complex transformation mechanism which has been observed repeatedly in α' needles (see Fig. 58). The α' has reverted to β phase with an α midrib rejected in the center of the needle. The base metal and heat-affected zone reveal two modes of precipitation depending on quenching rate in a way similar to the Ti–Al structures (see Fig. 36).

The bend ductility is always excellent, but strength is only 110,000 psi; heat treatments do not help to raise it. The longitudinal free-bend and the two guided-bend test methods differentiate between ductile and brittle be-

Table 11—Nominal and Actual Compositions of 25V – Ti Base Alloys

Test Nos.	Heat No.	Alloy (nominal), wt-%	Composition (actual), wt-%					
			V	Fe	C	N	O_2	H_2
4194–4213	7505	25V	23.9	(0.08)	(0.04)*	(0.02)	(0.09)	(0.016)
4214–4233	7619	25V – 0.1C	25.1	(0.08)	0.161	(0.02)	(0.09)	(0.016)
4234–4253	7620	25V – 0.2C	25.5	(0.08)	0.231	(0.02)	(0.09)	(0.016)
4254–4273	7617	25V – 0.3C	25.1	(0.08)	0.337	(0.02)	(0.09)	(0.016)
4334–4353	7505	25V – 0.1N	25.5	(0.08)	(0.04)	0.16	(0.09)	(0.016)
4354–4373	7653	25V – 0.2N	24.3	(0.08)	(0.04)	0.22	(0.09)	(0.016)
4374–4393	7633	25V – 0.3N	25.4	(0.08)	(0.04)	0.31	(0.09)	(0.016)
4274–4293	7616	25V – 0.1O_2	25.4	(0.08)	(0.04)	(0.02)	0.39	0.074
4294–4313	7632	25V – 0.2O_2	25.1	(0.08)	(0.04)	(0.02)	0.35	0.10
4314–4333	7636	25V – 0.3O_2	25.6	(0.08)	(0.04)	(0.02)	0.37	0.058

* Figures in parentheses indicate average content.

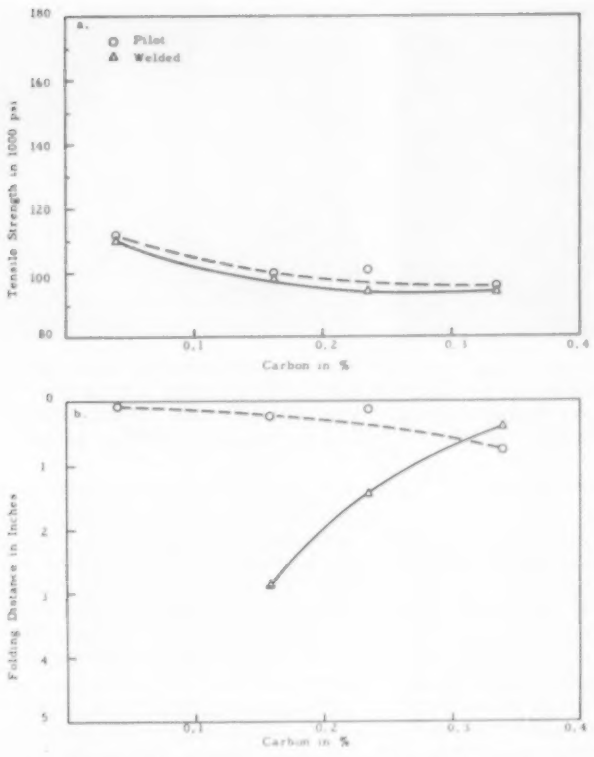

Fig. 62a and b Mechanical properties of weldments vs. C addition. 25V–C–Ti sheet; as welded

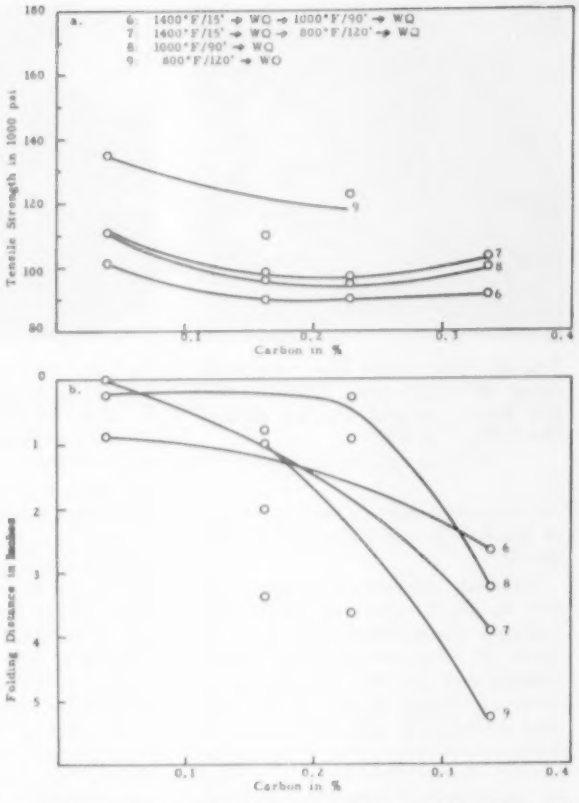
a.
6: 1400°F/15' → WQ → 1000°F/90' → WQ
7: 1400°F/15' → WQ → 800°F/120' → WQ
8: 1000°F/90' → WQ
9: 800°F/120' → WQ
Tensile Strength in 1000 psi
Carbon in %
b.
Folding Distance in Inches
Carbon in %

Fig. 64a and b Mechanical properties of weldments vs. C addition. 25V–C–Ti sheet; posttreated

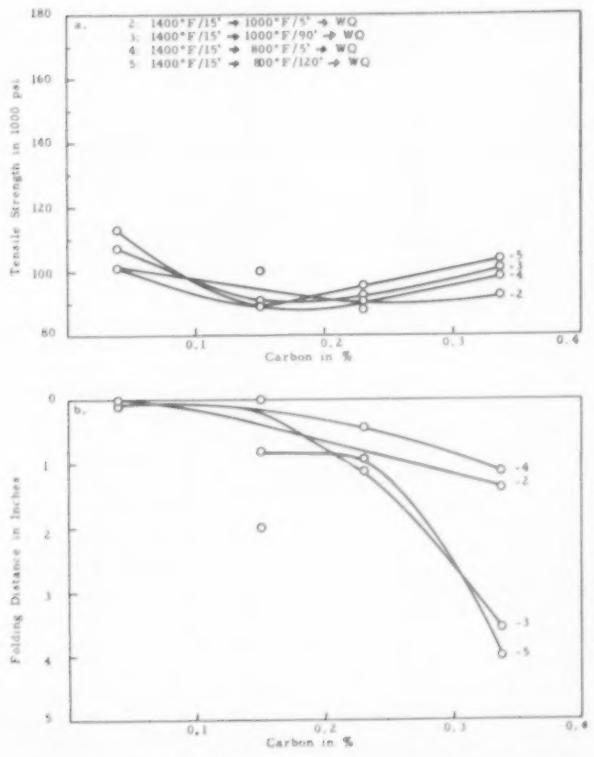
a.
2: 1400°F/15' → 1000°F/5' → WQ
3: 1400°F/15' → 1000°F/90' → WQ
4: 1400°F/15' → 800°F/5' → WQ
5: 1400°F/15' → 800°F/120' → WQ
Tensile Strength in 1000 psi
Carbon in %
b.
Folding Distance in Inches
Carbon in %

Fig. 63a and b Mechanical properties of weldments vs. C addition. 25V–C–Ti sheet; posttreated

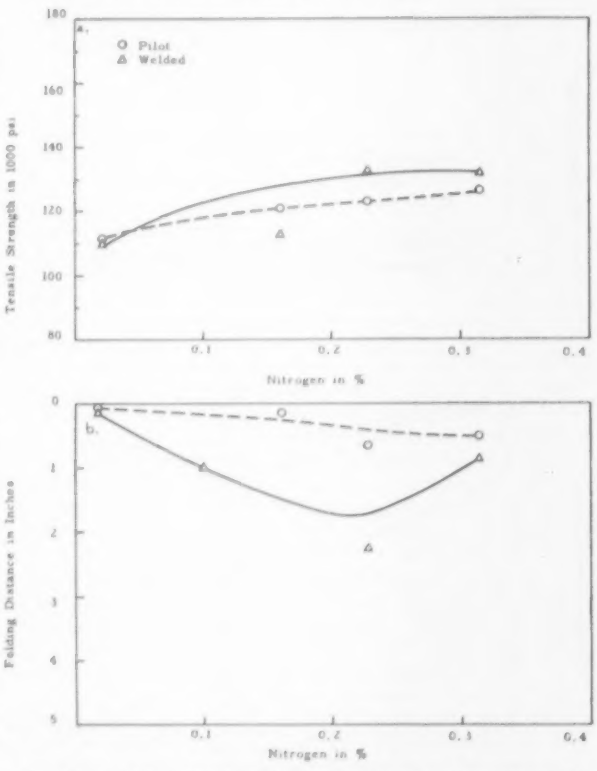

Fig. 66a and b. Mechanical properties of weldments vs. N addition. 25V–N–Ti sheet; as-welded

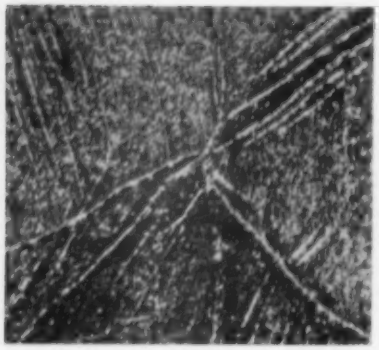

Fig. 65 Base metal 25V – 0.23N–Ti, under polarized light. UTS 133,800 psi; folding distance $2^1/_4$ in.; elongation 3.5%. ×500

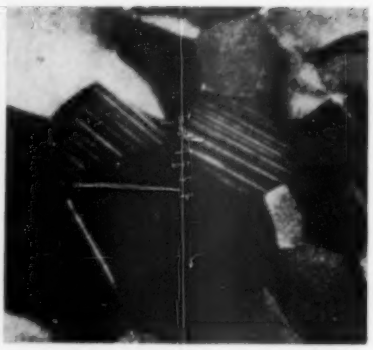

Fig. 69 Heat-affected zone 25V – 0.35O_2–Ti, annealed 90 min at 1000° F. UTS 135,800 psi; folding distance $2^1/_{16}$ in.; elongation 3%. ×150

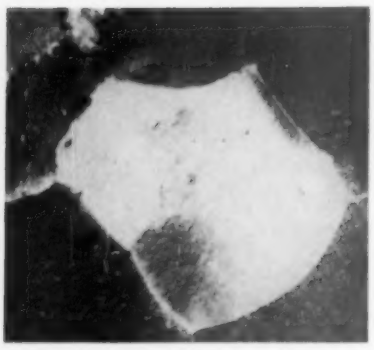

Fig. 70 Heat-affected zone 25V – 0.37O_2–Ti, annealed 2 hr at 800° F. UTS 141,600 psi; folding distance $2^3/_8$ in. elongation 3.5%. ×500

havior more sensitively than in the case of the 5Al–Ti and 7Al – 3Mo–Ti base alloys.

Nominal interstitial additions to 25V–Ti are 0.1, 0.2 and 0.3%. The analyzed compositions are listed in Table 11. The vacuum fusion determinations of the three oxygen-bearing alloys are closely similar; at the same time hydrogen is high. The cause is suspected to have been either incompletely cleaned second-melt electrodes or insufficiently degasified vanadium chips, or pickling of the sheet.

(4) 25% Vanadium – Titanium with Carbon Addition

Discussion of the carbon effect on weld structures is restricted because the ternary Ti-V-C system is not known. Carbides are present in almost all zones and with almost all additions. Carbides form either as pear-shaped particles or as Widmanstatten plates in the weld metal (see Figs 59, 60 and 61). Their effect on the reduction of grain size is obvious; the base metal of Fig. 59 contains 0.23 C and consists of equiaxed β-grains with α in the grains and grain boundaries; the pear-shaped carbides are elongated in the plane of rolling. The weld metal of Fig. 60 contains 0.23 C and consists of coarse β grains, fine α precipitates and Widmanstatten carbide. The weld metal of Fig. 61 contains 0.34 C and, therefore, has a denser population of fine carbide plates. They do not embrittle the predominantly β-phase structure.

The as-welded sheet is not strengthened by carbon (see Fig. 62*a*); neither is the pilot. Step quenching does not increase weld strength; the upward trend at high-C content is uninteresting (see Fig. 63*a*). The quench-and-re-

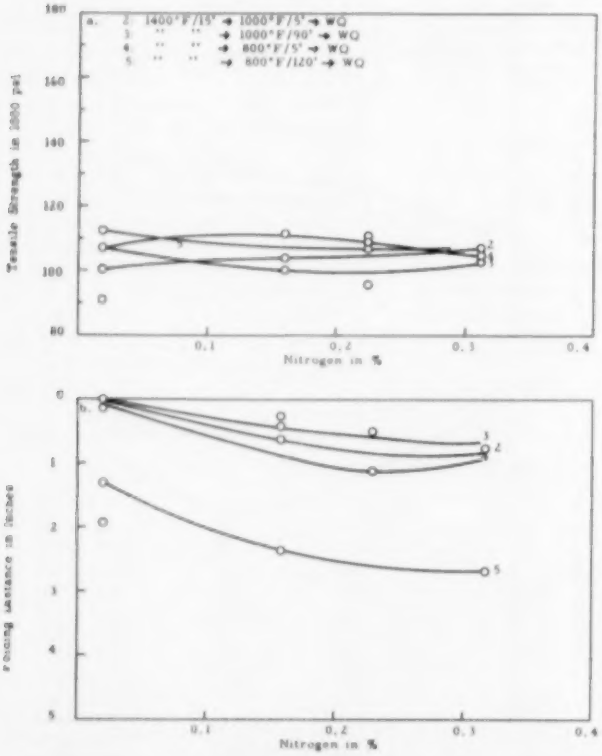
a.
2: 1400°F/15' → 1000°F/5' → WQ
3: " " → 1000°F/90' → WQ
4: " " → 800°F/5' → WQ
5: " " → 800°F/120' → WQ
Tensile Strength in 1000 psi
Nitrogen in %
b.
Folding Distance in Inches
Nitrogen in %

Fig. 67*a* and *b* Mechanical properties of weldments vs. N addition. 25V–N–Ti sheet; posttreated

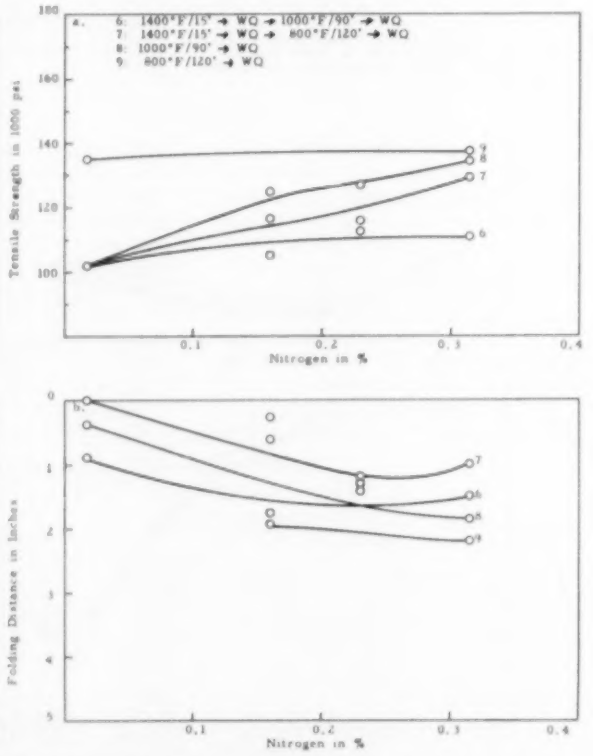
a.
6: 1400°F/15' → WQ → 1000°F/90' → WQ
7: 1400°F/15' → WQ → 800°F/120' → WQ
8: 1000°F/90' → WQ
9: 800°F/120' → WQ
Tensile Strength in 1000 psi
Nitrogen in %
b.
Folding Distance in Inches
Nitrogen in %

Fig. 68*a* and *b* Mechanical properties of weldments vs. N addition. 25V–N–Ti sheet; posttreated

heat type post anneal is not better (see curves 6 and 7, Fig. 64*a*). The simple reheat type treatment at low ($\alpha + \beta$) temperature is the only one appreciably strengthening the weld. Again, however, this is caused by the mechanics of α precipitation rather than by carbon (curve 9 in Fig. 64*a*). Preheat treatment does not strengthen the weldment.

Carbon does not embrittle the pilot sheet, but 0.1 to 0.2 C embrittles the weld metal. When more C is present, it does not affect weld ductility (Fig. 62*b*). Step-quench anneal renders medium-C weldments reasonably ductile, but reverses the trend by embrittling high-C specimens (Fig. 63*b*). Quench-and-reheat type treatments also make medium-C weldments ductile and high-C specimens brittle (Fig. 64*b*); only postheat-treated weldments with high C content embrittle. Carbon has no merits as strengthener but is inoffensive in small amounts after heat treatment; however, 0.16 C embrittles as-welded sheet.

(5) 25% Vanadium-Titanium with Nitrogen Addition

A typical untreated base metal structure shows strain line precipitation of α caused by local deformation stresses after rolling (see Fig. 65).* [7, 8] Similar structures were observed in nitrogen bearing 5Al–Ti.

Nitrogen which is a potent strengthening, hardening and embrittling agent in α titanium does not embrittle the β titanium pilot, and weldments containing 0.16 and 0.31 N are still within the 1-in. limit of free bend ductility. Nitrogen increases the weld strength from 110,000 to 130,000 psi in the as-welded state. Step-quench type anneals nullify this effect. Low-temperature quench-and-reheat type and simple reheat type anneals also raise the strength to 130,000 psi (Figs. 66*a* to 68*a*).

Weld ductility is good but erratic due to the nitrogen initiated strain line precipitation. Step-quench type treatments which remove the strengthening effect also make the weldment ductile (Figs. 66*b* to 68*b*). In general, any nitrogen strengthening endangers weldability either by outright embrittlement or by premature failure.

(6) 25% Vanadium–Titanium with Oxygen Addition

The ternary Ti-25V-O_2 system is not known. The precipitation has features similar to, as well as different from the nitrogen effects discussed in the preceding section. The as-welded sheet is all β phase with α' needles caused by local stresses. The long, high-temperature step-quench type anneal results in three characteristic phenomena: α precipitates preferentially at β grain boundaries; it precipitates throughout some β grains as fine globules; the interior of streaks always shows α precipitation. The transformation into all α grains begins with dense striations in certain areas of a coarse β grain. The heat-affected zone, after simple reheating to 1000° F, shows under polarized light the contrast among the unevenly advanced stages of transformation in the various grains of Fig. 69. The striking difference from the carbon effect is evident from comparison with the weld metal of Fig. 61 after identical heat treatment. In Fig. 69 four stages are visible: (a) the dark β phase; (b) globules in the small grains; (c) parallel bundles of striations running in almost the same direction in different grains due to identical stress direction. The large β grain contains strain lines only in its lower right-hand end; they will eventually cause this part to separate as an all α grain. (d) Several grains have become all α and appear uniformly white in definite positions when rotated under polarized light. The structure after simple reheat type 800° F anneal is shown in Fig. 70 which also presents the various stages of transformation under polarized light. Some grains have completed their transformation, others are in the striation stage and some are predominantly β except for their boundaries. The two dark grains show subgrains elongated in the plane of the sheet.

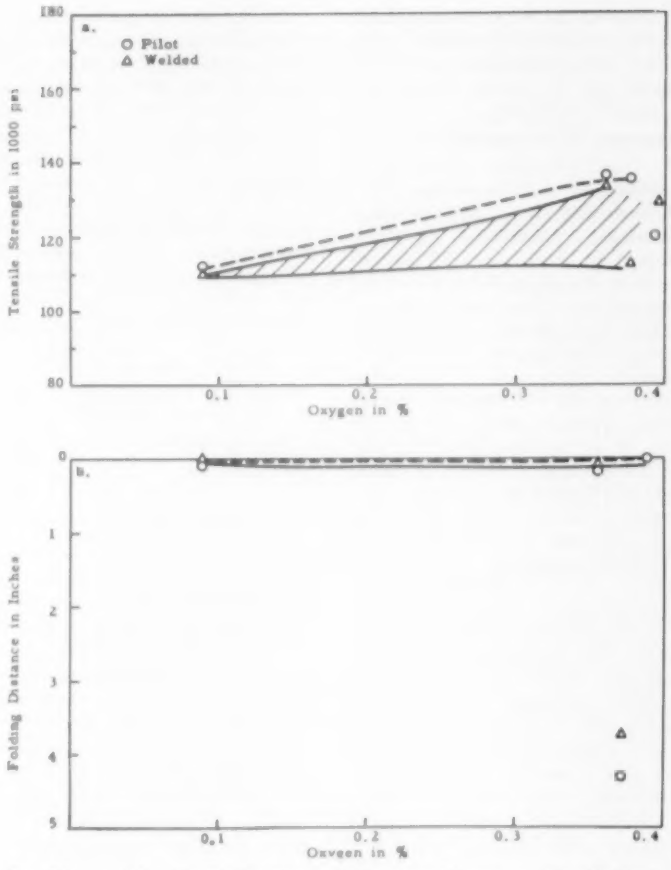

Fig. 71*a* and *b* Mechanical properties of weldments vs. O_2 addition. 25V – O_2–Ti sheet; as-welded

Tensile strength increases by oxygen addition to 120,000 psi (Fig. 71*a*). Step-quench type anneals raise the welded strength to 135,000 psi (Fig. 72*a*); quench-and-reheat type treatments have the same effect (Fig. 73*a*). Simple-reheat-type anneals strengthen to 143,000 psi (Fig. 73*a*, Nos. 8 and 9).

From the bend tests it is evident that 0.4% O_2 is not the limit of weldability and that higher oxygen alloys are a possibility, with any strength advantage they might possess. Ductility in the as-welded sheet is excellent (Fig. 71*b*) although tensile elongation is only fair. The long step-quench treatment reduces ductility to the 1-in. limit (Fig. 72*b*). Ductility remains constant for the quench-and-reheat type and the high-temperature reheat treatment (Fig. 73*b*). Since strengthening of the

* Structures of Figs. 6*a* and 6*b*[8] of Ti-N alloy show similar discontinuous striations.

same magnitude as in posttreated sheet is achieved without embrittlement in the as-welded state, oxygen-bearing 25V–Ti weldments are a possible answer for room temperature service.

(7) Summary—Vanadium-Titanium System

Hope for truly β stable weldments in alloys containing up to 30% V must be abandoned. Even when ductile β is retained in weld zones of specific compositions its metastability is cooling-rate dependent. This means that unintentional short anneals, as they occur in heavy cross sections, would effect mechanical properties adversely. Nevertheless, the V-Ti study is of fundamental interest. Brittle β' can be avoided in any of the 25V weld zones. As-welded strength, however, is below 100,000 psi; hope is held out that oxygen bearing 25 V alloys with over 0.4% O_2 will produce weldable sheet of over 130,000 psi strength.

Of the 4, 8, 15, 25 and 30% V compositions only the 15 and 25% alloys were studied for weldability and only the 25% alloy was contaminated with interstitials. Mechanical properties of the 15% V weld zones are affected by three structural features, β', α size and α shape. Heat treatments restore weldability and strengthen the as-welded sheet by 10%. The 1000° step-quench type treatment yields properties superior to those of the 1200° F treatment.

The 25 V weldment without interstitial additions is very ductile but weak. All four bend test methods become more sensitive with 25V–Ti. Heat-affected zone and weld metal retain ductile β; the base metal contains stain-line α precipitate. No postheat treatment strengthened the alloys without embrittlement. Quench-and-reheat type postheat treatment produces globular precipitation in β phase, similar to the precipitation in certain Ti–Al structures.

Oxygen causes similar striations which frequently lead to all-α grains; it does not affect weldability up to 0.4% O_2 content. Therefore, no postheat treatments are required and strength without brittleness of the weld zones possibly can be further enhanced by higher additions.

Although this was a fundamental study of the interstitial effects on weldability, some optimum strength-ductility combinations have been collected:

Ultimate tensile strength, psi	*Folding distance, in.*	*Composition, wt-%*	*Postheat treatment*
120/130,000	1	25V – 0.3N_2	1400°/15 min—WQ—800°/120 min
130/140,000	0	15V	1450°/15 min—WQ—1000°/60 min
	1/16	25V – 0.4O_2	as-welded

The α' needles are subject to a complex transformation mechanism already observed with 10% Mo–Ti weldments.

Carbon produces pear-shaped carbides and, in the weld metal, Widmanstatten plates. Carbon strengthens very little, but does not embrittle when postheat treatments are applied.

Nitrogen produces the strain-line precipitation known from Ti-Al weldments; it increases welded strength but at the cost of embrittlement.

V. Conclusions

Three interstitial elements, carbon, nitrogen and oxygen, impair the weldability of titanium alloy sheet. To quantitatively evaluate their effects three typical base alloys containing small additions were welded without filler material. The alloys were:

A binary α alloy: 5% Al – Ti.

A ternary alloy containing an α and a β strengthening element: 7% Al – 3% Mo – Ti.

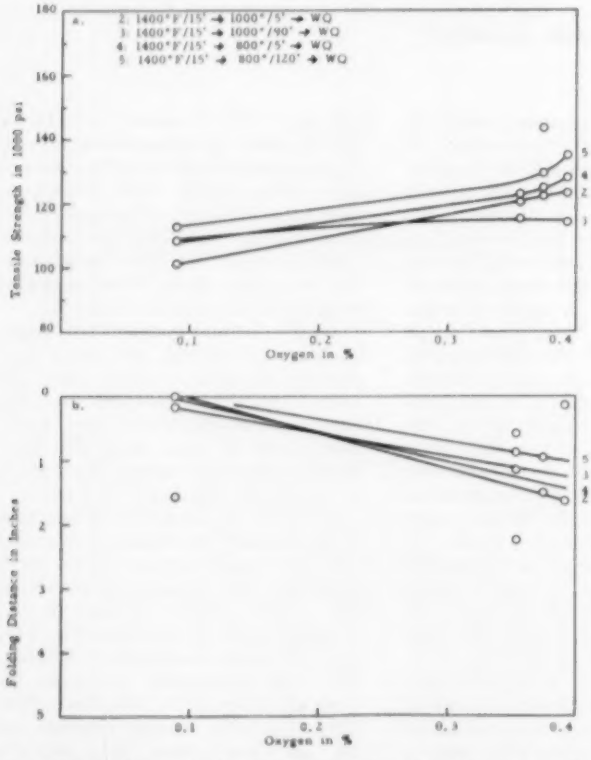
a.
2: 1400°F/15' → 1000°/5' → WQ
3: 1400°F/15' → 1000°/90' → WQ
4: 1400°F/15' → 800°/5' → WQ
5: 1400°F/15' → 800°/120' → WQ
Tensile Strength in 1000 psi
Oxygen in %
b.
Folding Distance in Inches
Oxygen in %

Fig. 72a and b Mechanical properties of weldments vs. O_2 addition. 25V–O_2–Ti sheet; posttreated

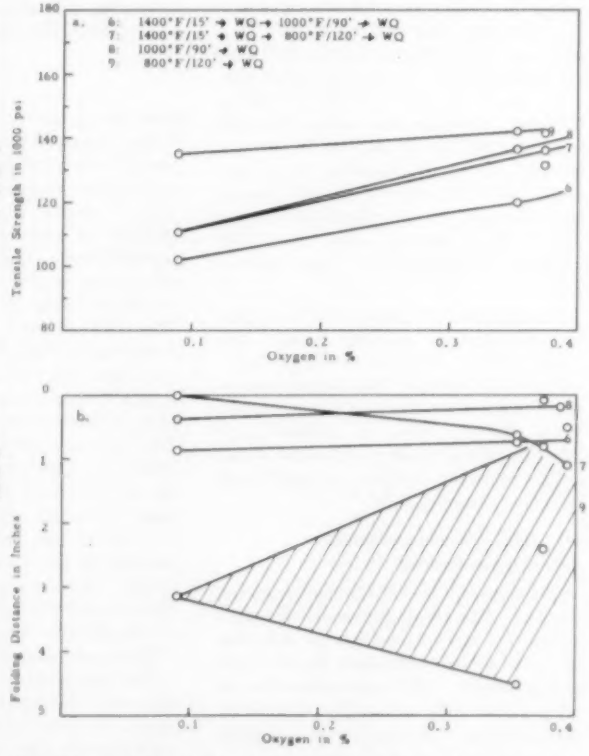
a.
6: 1400°F/15' → WQ → 1000°F/90' → WQ
7: 1400°F/15' → WQ → 800°F/120' → WQ
8: 1000°F/90' → WQ
9: 800°F/120' → WQ
Tensile Strength in 1000 psi
Oxygen in %
b.
Folding Distance in Inches
Oxygen in %

Fig. 73a and b Mechanical properties of weldments vs. O_2 addition. 25V–O_2–Ti sheet; posttreated

A binary β alloy: 25V – Ti.

Weldability was to be determined essentially by bend ductility, while other mechanical properties of unwelded and welded sheet were also investigated. Typical heat-treatment cycles were to be selected for each individual alloy and interstitial addition to establish trends for restoring ductility, or strength, or a combination of both.

Limits of addition in 5Al–Ti proved to be 0.20% for carbon, 0.18% for nitrogen and 0.25% for oxygen. These interstitial contents strengthened the weldments to various degrees.

No general pattern emerged for 7Al – 3Mo–Ti. Carbon and nitrogen produced brittle weldments under certain specific conditions, but none under others. Oxygen, at the 0.15% level, yields a strong, ductile structure after either a short-time, step-quench type or a long-time, low-temperature anneal.

The 25V–Ti alloy showed little effect from carbon additions. Nitrogen which strengthens the weldment, did produce erratic ductility results. Oxygen additions displayed no deleterious effect on weldability; as-welded sheet was strong and ductile. The 0.4% addition does not appear to be the limit.

Interesting side developments were the production of workable, weldable 8Al–Ti, whereas 7Al–Ti was indicated in the past as the forgeable limit by many investigators. Also 15V–Ti displayed an unorthodox, but promising response to low-temperature isothermal anneals.

Microstructures were methodically used to explain the mechanical properties of the welded zones, and several structural phenomena of major interest were uncovered.

Hardness was not a satisfactory indicator of brittleness in weld zones; it was, however, put to good use for controlling the contamination of the α alloy during preparation from the melt.

It may be concluded that interstitial elements in titanium alloy weldments are harmful under some conditions. Where possible, limits of usefulness have been described; they will have to be supplemented by impact tests with heavier stock. Under some conditions the interstitial elements carbon, nitrogen and, especially, oxygen show promise as strengtheners at not too high a cost of ductility, and may be valuable, if strictly controlled, as inexpensive alloying additions already present in titanium sponge. This fundamental study should help to enlarge and clarify the range of weldable titanium-alloy compositions. At the same time, heat treatments that will restore ductility after embrittlement by the welding cycle are described in terms of the individual phase relationships.

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THE EFFECT OF SPECIMEN SIZE

(*Continued from page 483-s*)

for mechanical polishing. The 2.20-in. specimens had the same fatigue strength as the 1.26-in. With electrolytic polishing the fatigue strengths were 33,300 psi at 0.08 in. diam and 31,500 psi at 1.26 in. diam. The size effect in rotating bending is believed to be related to the fact that stress and strain are out of phase due to elastic hysteresis. No trend could be derived from the alternating torsion tests.

In the tension-compression tests, fatigue strengths were 4% higher at 8500 cpm than at 1500 or 350 cpm. There was no systematic difference among the rectangular, square and circular cross sections in alternating bending. The ratio of fatigue strength in alternating torsion to fatigue strength in tension or bending varied from 0.52 to 0.65 among the series.

The effect of a notch depended on whether it was electrolytically polished. In tension-compression tests the fatigue strength of mechanically polished specimens passed through a minimum as notch acuity increased. The decrease was continuous, on the other hand, with electrolytic polishing. This effect was not observed in alternating torsion, nor was it too clear in tension-compression. It was the most severely notched specimen that showed the increase in fatigue strength mechanically polished. Yet this most severe notch could not be included in the electrolytically polished series. The notch results agreed closely with those of R. E. Peterson (*Stress Concentration Design Factors*, John Wiley & Sons, New York, 1953). Grain size had little effect on these results, although the medium and coarse grains seemed to be less sensitive to notches. The dispersion of results was greater for the medium and coarse grains than for the fine grains.

The effect of stress gradient is shown in Table 1. The size of the hole, which governs the stress gradient, had considerable effect on the fatigue strength.

Table 1—The Effect of Stress Gradient on Fatigue Strength in Tension Compression

Diam of hole, in.	*Width of specimen, in.*	K_t	*Gradient, nominal stress*	K_f	*Fatigue strength, psi*	Q
0.02	1.77	2.98	27.85	1.60	21,100	0.303
0.04	1.77	2.96	13.85	1.73	19,500	0.372
0.08	1.97	2.92	6.87	1.81	18,700	0.423
0.16	2.36	2.88	3.40	1.93	17,500	0.495
0.32	2.52	2.77	1.697	1.99	16,800	0.560
0.63	2.52	2.56	0.796	1.80	18,800	0.513
1.26	2.75	2.24	0.391	1.69	19,900	0.556

K_t = stress concentration factor. K_f = ratio of fatigue strengths in the unnotched and notched conditions. $Q = K_f - 1/K_t - 1$.

ROOM TEMPERATURE CRACK PROPAGATION AND SIZE EFFECT ON MILD STEEL

Some observations on the nature and behavior of fracture in mild steel during room temperature notch-bend tests

By J. D. LUBAHN

ABSTRACT: In room temperature notch-bend tests on mild steel, more-or-less deep gradual tearing is followed by one sudden cleavage failure, or by intermittent cleavage, depending on the size and geometry of the specimen. In general, as the size increases, the cleavage begins earlier and extends farther, and thus is more severe. Neither large width nor large depth alone is sufficient to cause this size effect, if the other dimensions are small.

On the other hand, the ductility (strain up to crack initiation) is not affected by size in the range from 0.08-in. beam depth to 4-in. depth. "Ductility" as used here is defined with some arbitrariness, because of the very gradual manner in which cracks begin to open up.

Where examined microscopically, "cleavage" fracture was found to consist mostly of crystallographic cleavage, but containing also a variety of other energy-absorbing features.

The ductility in the thickness direction of 4-in. hot-rolled mild steel plate is very poor. Consequently, in a specimen cut in the rolling direction, with the notch in the transverse direction of the plate, the crack starts high on the notch radius rather than at the notch bottom, and progresses in the rolling plane for a short distance before turning, and going across the depth of the specimen. Under these conditions, the apparent ductility even in the rolling direction is abnormally low.

Most of the energy absorbed in small specimens occurs while the crack is propagating across the specimen. Only about 15% is absorbed prior to crack initiation. Thus, absorbed energy is a quantity which may be more dependent on the mode of crack propagation than on ductility. This statement applies also to reduction of area, or other dimensional changes, when measured after complete separation of the specimen. Maximum load may also be influenced by the mode of crack propagation.

The Mechanical Behavior

In notched-bend tests on mild steel at room temperature, the fracturing commences at (or very near) the tension surface. Under these conditions it is possible to describe the nature of the fracture during its entire course from initiation to complete separation of the specimen into two pieces.

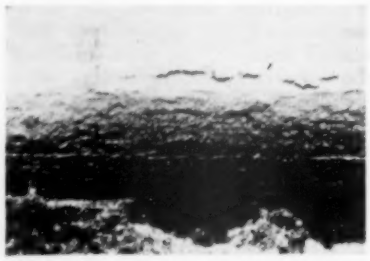

Fig. 1. View normal to notch surface at tangent point, showing cracks similar to those that caused failure on the other side of the notch. Dark area is lapped surface of notch radius. × 5

The most commonly observed crack-propagation behavior is as follows. The first microscopic cracks appear near mid-width on the tension side of the specimen, Fig. 1. As bending proceeds, some of these small cracks gradually join together into a wider and deeper crack whose size overshadows that of prior cracks which had not participated in the joining-together process. This larger crack spreads toward the side faces of the specimen as it becomes deeper in the middle and eventually leads to final separation of the specimen. After the crack has proceeded by gradual tearing to a point that is more or less deep into the specimen, depending on conditions to be described later, there is a loud noise, the crack suddenly proceeds all the rest of the way across the specimen (or nearly so), and the load drops off to a comparatively small value. If complete separation does not occur there may be a thin wall of solid metal across the bottom and up both sides of the specimen, sometimes nearly up to the tension surface, Fig. 2. When a deep crack at mid-width does not extend to the side faces, there is often external evidence of this deep internal crack in the form of shallow grooves in the side faces, Fig. 2, where stretching of the surface layer has caused a local neck, as in a tensile test. If one continues to bend such a specimen some more, so that complete separation occurs, the metal at the side faces separates on shear planes, which give rise to a 45-deg "shear lip" at each side of the specimen,[1] and the layer across the bottom of the specimen gradually tears. The tearing of the thin edge at the bottom is accomplished by an enormous increase in the bend angle[1] and very large plastic flow. Thus, fibrous fracture may occur along all four edges of the fracture surface, giving rise to what has sometimes been called the "picture frame" effect. The fibrous zone along the notch bottom precedes the cleavage, and that along the other three edges follows the cleavage. As the testing temperature is lowered the "picture frame" becomes narrower, and finally disappears.

A less common crack-propagation behavior consists of alternating gradual and sudden advances of the crack.

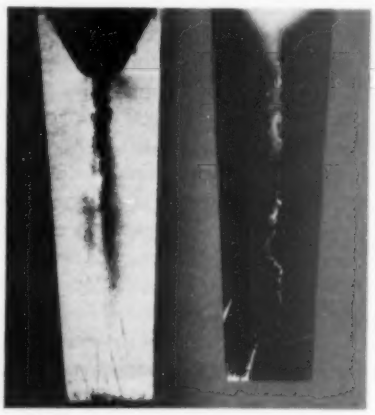

Fig. 2 Slow notch-bend specimen hanging together by shell after sudden crack propagation. Left photograph shows side face of specimen. Right photo shows section at mid-width

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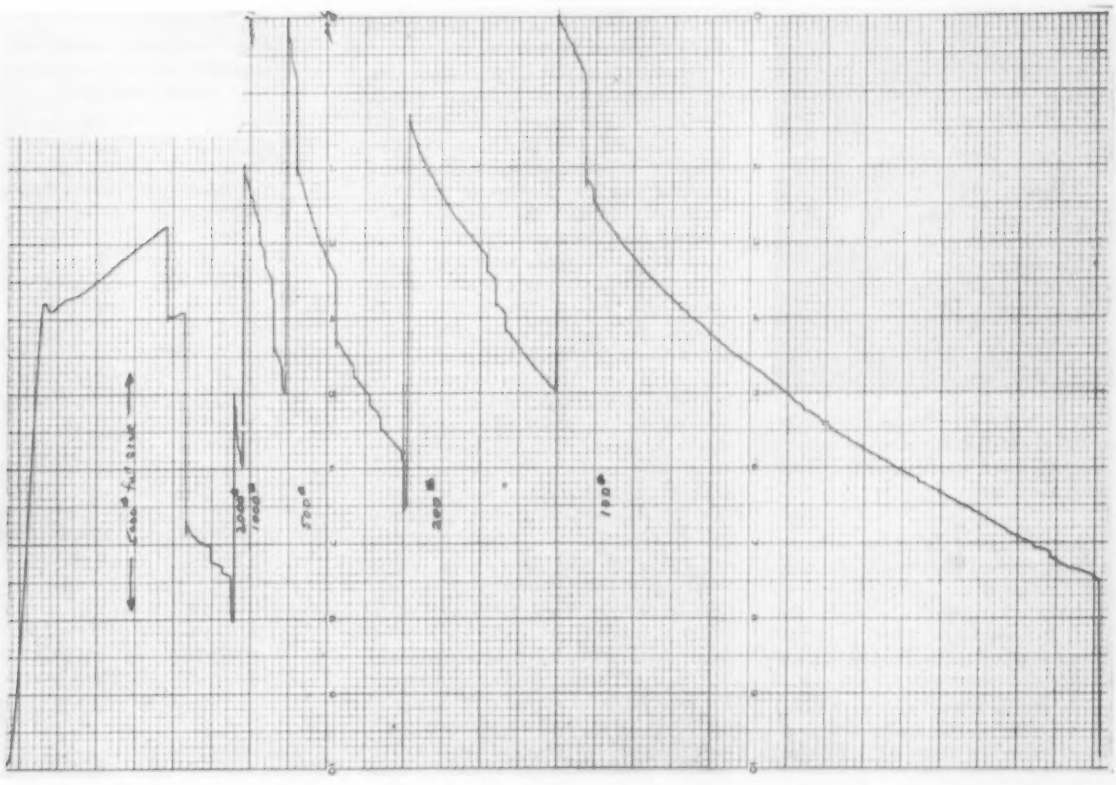

Fig. 3 Load-deflection curve for slow notch-bend test of mild steel, 2 in. wide by 0.394 in. deep. Forty-five degree V-notch 0.079 in. deep with 0.010 in. root radius. Tested on 4-in. span. Speed of crosshead: 0.2 ipm. Abscissa on chart record is head motion; smallest square = 0.01 in. of head motion. Yield point jog at beginning is due to prior straining (by bending) and aging

Fig. 4 Broken notch-bend specimen of mild steel. Two-inch square, with sharp 45-deg V-notch 0.4 in. deep. Slow-bend test on 11-in. span

Gradual tearing occurs first, as in the more usual pattern of behavior; but the subsequent sudden propagation of the crack, which is accompanied by a noise, does not continue very far—by no means all the way across the specimen. The load drops suddenly at this point, but only by a small fraction of the total load. Then gradual tearing proceeds again (usually with slightly decreasing load) for a short distance until the crack again advances suddenly, with accompanying noise and sudden load decrease. The cycle may be repeated several times before complete separation. The last increment of tearing is gradual, in the manner described previously. The load deflection curve shown in Fig. 3 illustrates the number and magnitude of load decrements accompanying the sudden advances of the crack.

A third, and still less common, crack propagation behavior consists of intermittent sudden advances of the crack. As before, the sudden advances are accompanied by a noise and a load decrement. Although considerable plastic bending occurs during the intervals of time between the sudden advances, apparently there is no gradual advance of the crack during these intervals. The process of intermittent, sudden crack propagation results in a crack which gapes open wider and wider with progressive bending, in the same manner as a crack which is progressing gradually (Fig. 4). This is in contrast to the case where most of the fracture surface is due to a single cleavage advance, where the subsequent fracture surfaces fit nicely, Fig. 5.

The Crystallographic Aspects

Generally speaking, there is a distinct difference in macro-appearance of the fracture surface of a piece of mild steel, depending on whether the crack has progressed suddenly or gradually. When the crack has progressed suddenly the resulting fracture surface shows many small reflecting facets, which are the cleavage faces of the individual grains. Hence the term "cleavage fracture" is often applied to the sudden fracturing described above. When the crack progresses gradually, the resulting fracture surface is dull gray and silky

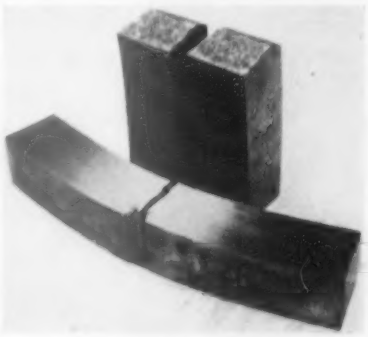

Fig. 5 Broken notch-bend specimen of mild steel. Two-inch square with 45-deg V-notch 0.4 in. deep and 0.050 in. root radius. Slow-bend test on 11-in. span

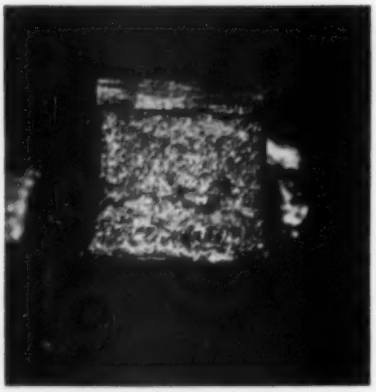

Fig. 6 Alternating fibrous and cleavage appearance in the fracture surface of a notch-bend specimen. Standard V-notch specimen

in appearance, and the term "fibrous" has been applied commonly to such fracture surfaces.

The microscopic state of affairs at the fracture surface which accounts for the macro-appearances described above can be observed conveniently for a standard V-notch Charpy-impact specimen which exhibited alternating sudden and gradual fracture. The macro-appearance of the fracture surface is shown by Fig. 6; two cleavage bands alternating with three fibrous bands are evident. The microsection across the depth of the specimen is shown by overlapping photomicrographs at × 220 in Reference 1, and typical portions are shown in Fig. 7. This section was made at 0.115 in. from the right hand face (as oriented in Fig. 6) the entire width at the notch bottom after fracture being 0.444 in. by micrometer measurement. These dimensions were also used to calibrate the apparent net depth of the beam as depicted in the photograph of Fig. 6; this net depth appeared to be 0.340 in.

Figure 7 shows two different characteristic appearances in different places. The appearance between the 40th and 44th in. in Fig. 7*b* is typical of one characteristic appearance, where the metal is pulled out into a series of points or "scallops" in much the same way that a sticky paste behaves when two blocks stuck with such paste are pulled apart without letting the paste dry. Figure 8 shows the same phenomenon more clearly (× 500). The appearance between the 46th and 53rd in. in Fig. 7*b* is typical of the other characteristic appearance, where many straight surfaces across grains are observed—presumably cleavage faces. The boundaries between regions showing these two characteristic appearances are not very clear-cut, but estimates of their locations are presented in Table 1. These locations are compared with boundaries picked from Fig. 6, the dimensions to the various boundaries being multiplied by a suitable ratio to give the same total beam depth as in the photomicrograph (75 in.). The comparison shows that the two kinds of appearance in Fig. 6 really do correspond to the two characteristic appearances in Fig. 7. The fibrous appearance to the naked eye corresponds to the scalloped appearance of the microsection, and the reflecting facets seen by the naked eye are the cleavage faces in the microsection. One exception to this correspondence is the fibrous patch picked up on the microsection from the 39th to 46th in. but which is not obvious in the macropicture. In subsequent tests it was a common experience that narrow fibrous bands, known to exist for other reasons, could not be detected with the naked eye in a larger region of cleavage.

Table 1—Boundaries Between Cleavage and Fibrous Regions —Two Methods

Fig. 6, Equivalent distance from notch bottom, in.		*Reference 1 (see also Fig. 7) distance on photomicrograph from notch bottom, in.*	
0	Fibrous	0	Fibrous
11¼	Cleavage	10	Cleavage
50¾	Fibrous	39	Fibrous
56½	Cleavage	46	Cleavage
65½	Fibrous	53½	Fibrous
75		57	Cleavage
		66½	Fibrous
		75	

The characteristic cleavage appearance is due to the presence of many cleavage faces; it is a common misconception that *all* of the fracture surface consists of cleavage faces, however, and this is not the case. Figure 9* shows a variety of effects which occur in conjunction with cleavage fracture, but which are not cleavage in themselves and which undoubtedly adsorb considerable energy.

Frequently, in either ferrite, Fig. 9*a*, or in pearlite,[1] several cleavage frac-

* Figures 8 and 9 are microsections from the specimen of Fig. 4.

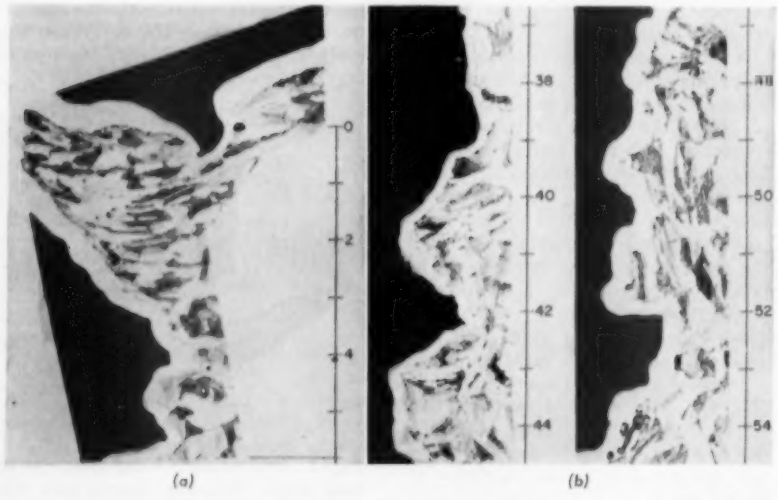

Fig. 7 Portions of microsection at X 220 across the depth of the specimen of Fig. 6 at 0.115 in. from the right-hand face. White area is nickel plating. (Reduced by one-fifth upon reproduction)

Fig. 8 Microsection of fibrous fracture. X 500

tures open up on parallel planes in a given grain, with subsequent tearing and bending required to join them into a continuous fracture path. This results in a stepped cleavage surface, which may occur either in ferrite, Figs. 9*b* and 9*c*, or pearlite, Fig. 9*d*. The occurrence of more than one cleavage fracture in a grain was previously noted by Low.[2]

In addition to the main fracture path, many secondary cracks branch off into the metal. These usually stop at a grain boundary, and sometimes within a grain, with considerable plastic flow occurring just beyond the point where the crack stops. The plastic flow is evident from the fact that the crack gapes open widely, Fig. 9*d*, and may be quite rounded at the end.[1] The grain boundary which stops the crack may be a ferrite-to-ferrite boundary, Fig. 9*c*, or a ferrite-to-pearlite boundary. In the latter case the crack may have been advancing either through the ferrite grain, Fig 9*d*, or the pearlite grain, Fig. 9*e*. The crack occasionally may stop in the middle of a pearlite grain, Fig. 9*f* or in a ferrite grain, Fig. 9*g*.

When secondary cracks have isolated a thin projecting piece of metal, this projection may suffer severe plastic shear[1] or bending, Fig. 9*b*, because of interference with projections across the main fracture.

Even though the ferrite grains and usually also the pearlite grains consistently fail by cleavage, Fig. 9*d*, there may be other pearlite grains which fracture in an irregular manner, Fig. 9*f*.

Although the cleavage planes are usually very flat, they are sometimes slightly warped.[1] Occasionally the fracture surface appears to be very smooth, as with cleavage, but far from a flat plane, Fig. 9*g*.

Thus, there are at least five depar-

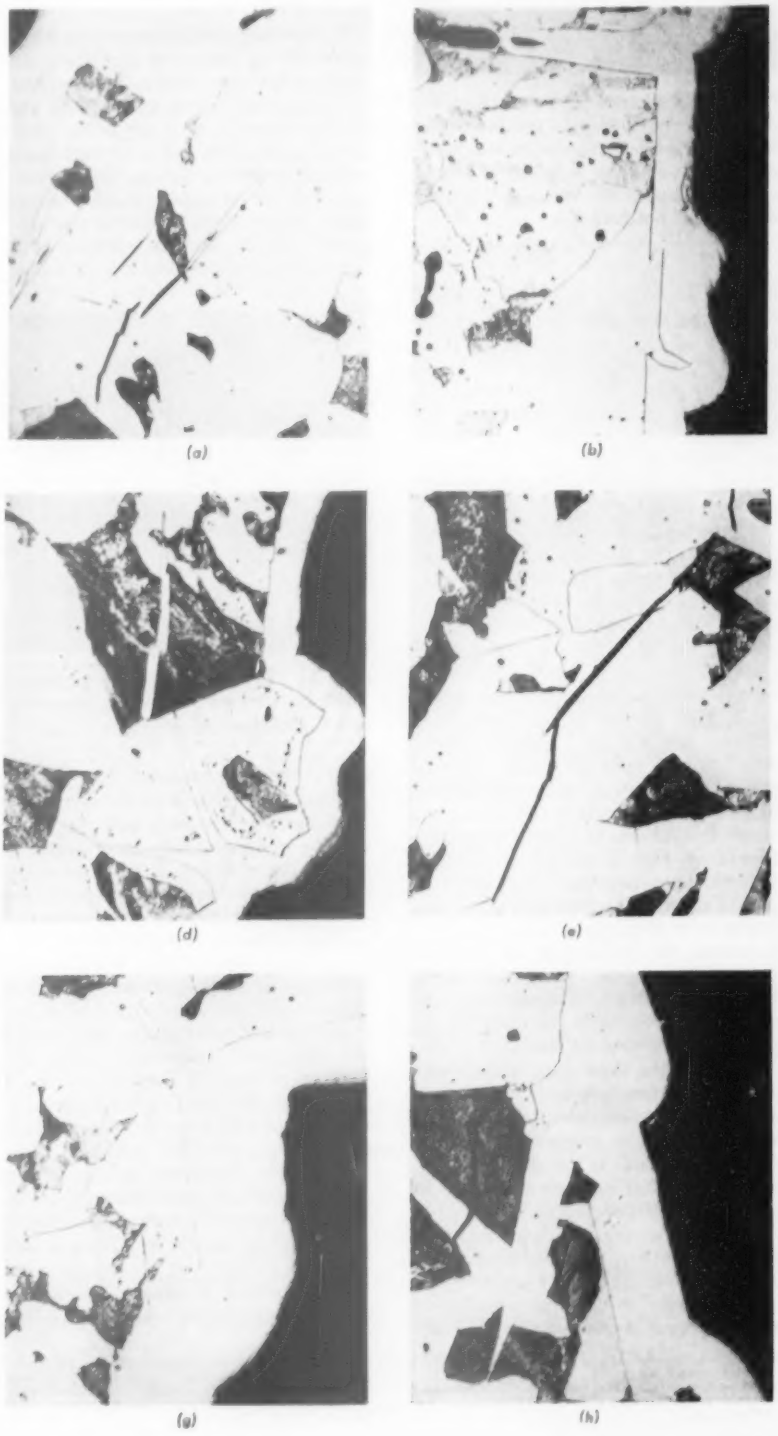

Fig. 9 Microsections at fracture surface of specimen of Fig. 4. × 500. (Reduced by one-half upon reproduction)

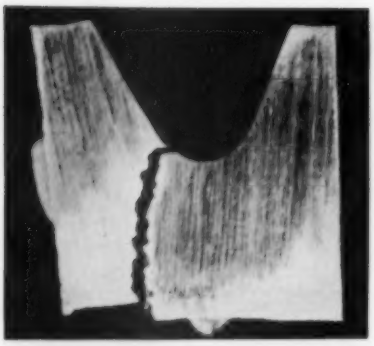

Fig. 10 Section through a portion of a mild-steel notch-bend specimen cut from 4-in. plate. Specimen was geometrically similar to a V-notch Charpy specimen, being 3.4 in. sq and having a 0.091 in. notch radius

tures in real metals from the idealized concept of pure cleavage: (*a*) tearing between adjacent cleavages in the same grain, (*b*) secondary cracks which are dulled by plastic flow at their terminus, (*c*) bending of isolated projections, (*d*) occasional lapses from the usual cleavage when the main fracture passes through pearlite and (*e*) slightly warped cleavage planes.

Figure 9 also reveals several interesting features of cleavage failure in both ferrite and pearlite. There may be cleavage on planes of more than one orientation in either ferrite, Figs. 9*b* and 9*g*, or pearlite, Fig. 9*h*. The orientation of the cleavage plane in a pearlite grain may be the same as in an adjacent ferrite grain, Figs. 9*b* and 9*d*, or it may be a different one, Fig. 9*h*. Internal* cracks may begin to open up within a ferrite grain, Fig. 9*a*, within a pearlite grain (1), or at a grain boundary. When an internal crack starts at a grain boundary, there may, Figs. 9*c* and 9*d*, or may not, Fig. 9*h*, be a cleavage plane which is part of the main fracture and which also impinges on the grain boundary in question near the location of the internal crack. Occasionally there will be a large cavity which is apparently not connected to the main fracture[1] (in the plane of the section, at least).

In hot-rolled mild steel, fibrous and cleavage fracture are easily recognized and definitely associated with gradual and sudden crack propagation, respectively. The same is probably true also for any steel having a structure that is predominantly free ferrite. For other structures, however, such as pearlite, tempered martensite or tempered bainite, the relationship between the mechanical and crystallographic aspects of crack propagation is much less clear-cut. In a heat-treated titanium boron steel,[3] for example, a picture-frame effect was observed in impact tests; but *both* regions appeared to be fibrous, comprising two shades of gray rather than two different surface textures. Also fracture modes other than cleavage or fibrous occur in other structures, such as grain-boundary fracture.*, [1]

Crystallography Vs. Mechanical Behavior

In the case of fractures which have only one occurrence of sudden crack propagation, the relation between the mechanics and crystallography of the fracture is fairly clear cut. The gradual tearing which starts at the notch bottom produces a fibrous fracture surface, and the subsequent sudden propagation of the crack results in cleavage except in its terminal stages. The cleavage spreads downward and outward until it approaches near to the side and bottom faces of the specimen, at which time the crack may return to the fibrous mode under certain conditions. The return to the fibrous mode before complete separation is quite obvious when the sudden crack propagation has not resulted in complete separation; in this case the final crack propagation occurs by gradual tearing. However, even when the sudden crack propagation results in complete separation, one often finds fibrous strips along the sides or bottom edge of the fracture;[1] apparently the inertia of the pieces is sufficient to tear open the thin shell of metal remaining after cleavage, even though the conditions necessary for cleavage have ceased to exist when the cleavage fracture has approached closely to the bottom and/or side faces of the specimen.

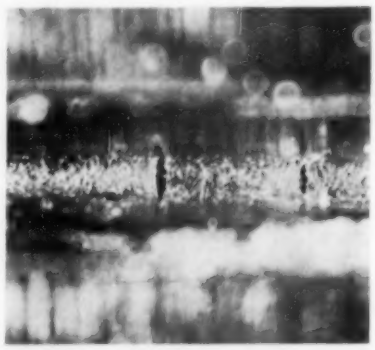

Fig. 11 Bessemer steel notch-bend specimen with cracks running crosswise in the notch bottom

When several increments of sudden fracture occur during one test, any one of at least three crystallographic appearances may result. One is the alternating cleavage and fibrous banding already noted, Fig. 6. A second consists of small equiaxed patches of cleavage distributed at random over the fracture surface, with the remainder being fibrous. A third type of crystallographic appearance accompanying intermittent, sudden crack propagation was observed in only one case. This was a 2-in. square bend bar with a 60-deg V-notch machine with as small a radius as possible (0.001 in. approx.) and tested at room temperature. This specimen showed plastic bending between the sudden crack advances, but no evidence of gradual tearing; the resultant fracture surface showed no fibrous fracture that was visible to the naked eye, and only one small region (approx. 0.005 in.) could be found in a microsection extending the full depth of the beam, Fig. 8. Another specimen which was identical except for a root radius of 0.050 in. exhibited a single cleavage failure beginning after about $^1/_{16}$ in. of fibrous tearing. Why the root radius might so affect the entire subsequent pattern of crack propagation will be discussed later.

Size Effect

In order to gain a better understanding of the size effect[5] in mild steel, notch-bend tests were conducted on two lots of 4-in., hot-rolled mild steel plate using specimens geometrically similar to the standard V-notch Charpy-impact specimen. Although the two lots of steel were nominally identical, both being open-hearth steels, Lot I was found to be somewhat more anisotropic than Lot II. This rather pronounced anisotropy in the Lot I steel was first observed in testing a $3^1/_2$-in. square scale model of a standard V-notch Charpy impact specimen.[6] The specimen was cut in the rolling direction, with the depth of the beam being in the thickness direc-

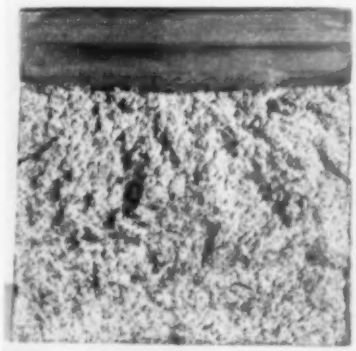

Fig. 12 Four-inch scale model of standard V-notch Charpy bar, showing fibrous fracture below center of notch bottom, but not extending out to side faces

* Not connected to the main fracture in the plane of the section, but conceivably connected with the main fracture above or below the plane of the section.

* Grain boundary fracture has also been observed in low-carbon steel under certain special circumstances.[4] In rare cases it can be found in mild steel under ordinary circumstances, Fig. 9*e*.

tion of the plate. When the longitudinal strain* at the notch bottom reached 45%, cracks began to appear high up on the notch radius on both sides, and extended approximately horizontally into the metal. Figure 1 shows a view of the cracks in one sidewall of the notch, after complete rupture of the specimen resulted from similar cracks in the opposite sidewall. Thus, the cracks in Fig. 1 appear approximately as the ones on the other side would have appeared just before complete rupture. The dark area in the photograph is the lapped surface of the notch bottom, so it can be seen that the cracks are clustered about a point slightly above the tangent point. On subsequent bending, when a load just below the highest previous load was reached, there was a loud report and the specimen broke in two. Figure 10 shows how the horizontal crack turned (after progressing about $^1/_{16}$ in.) and went vertically through the specimen. The vertical fracture had a "cleavage" appearance while the horizontal part looked "woody." Even after having gone part way through the specimen vertically, the crack had considerable tendency to go horizontally,[1] because of the very poor fracture resistance in the thickness direction of the plate. These tendencies have been noted also by Matton-Sjoberg[7] and Soete[8] (see also Fig. 14).

In the test discussed above, since no cracks were observed at the bottom of the notch, it must be presumed that the longitudinal ductility would be greater than 45% if abnormal fracturing had not been caused by the anisotropy. This possibility was investigated by comparing tests on standard-size notch-bend specimens with two different orientations; in both cases the long direction of the specimen was in the rolling direction, but the long direction of the notch was in the transverse direction of the plate in one case (Orientation A) and in the thickness direction of the plate in the other case (Orientation B). Two specimens of Orientation A (same orientation as the large specimen) developed cracks in the side of the notch at notch-bottom strains of only 35 and 55%,* while a specimen of Orientation B reached a notch-bottom strain of 65% before developing a crack at the notch bottom. Thus, the nature of the failure, as influenced by the anisotropy, had a definite effect on the apparent ductility in a *given* direction.

Presumably the anisotropy could also affect the character of the fracture in a specimen of Orientation B, if the fracture properties in the thickness direction of the plate (long direction of the notch) were so poor that the tension developed along the notch bottom due to restraint[6] could cause longitudinal splitting. This effect was not observed in the open-hearth steel discussed above, but it was observed in a Bessemer steel, Fig. 11. The effect has also been observed by Siegfried[9].

The abnormal fracturing noted in Lot I steel due to anisotropy was not observed in Lot II steel; the fracture propagated generally downward from the notch bottom, and specimens with A and B orientations had essentially the same ductility (Table 2). The anisotropy was further investigated by making wide, unnotched bend[3] tests (plane strain; biaxiality approximately = 0.5) in various directions, Table 3. The results show that the ductility in the thickness direction of the plate is much smaller than in the other two directions for both lots, and that the Lot I material is somewhat more anisotropic (greater difference in ductility between rolling and normal direction).

Comparison of ductility values in Table 2 for Lot I steel with Orientation A shows 45% for the $3^1/_2$-in. specimen and an average of 45% for two 0.4-in. specimens. From these few tests covering a factor of only nine in size it may be tentatively concluded that there is no effect of size on the ductility, or the strain up to the beginning of a crack. On the other hand, size has a very pronounced effect on the way the crack propagates. In the large specimen,

Table 2—Notch Bending Ductility of Mild Steel in the Rolling Direction (Percent Elongation at Notch Root)

Size of square, in.	*Notch in transverse direction*	*Notch in normal direction*
	Lot I material (highly anisotropic)	
0.4	35	65
	55	
3.5	45	
	Lot II material (slightly less anisotropic)	
0.08	86	
	104	
0.4	76	67
		105
2	79	
	92	

* Strain was measured directly on gage lengths on the notch bottom.[4] In smaller specimens described below, the strain was calculated from the bend angle.[5]

* Ductility values in mild steel at room temperature are subject to some uncertainties because of the difficulty of defining "the beginning" of tearing. This difficulty will be discussed in more detail later.

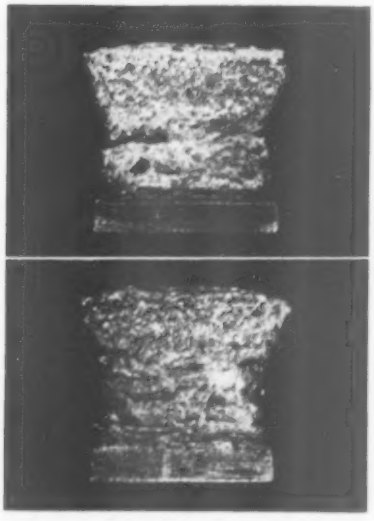

Fig. 14 Fracture surface of specimen of Fig. 13. × 3

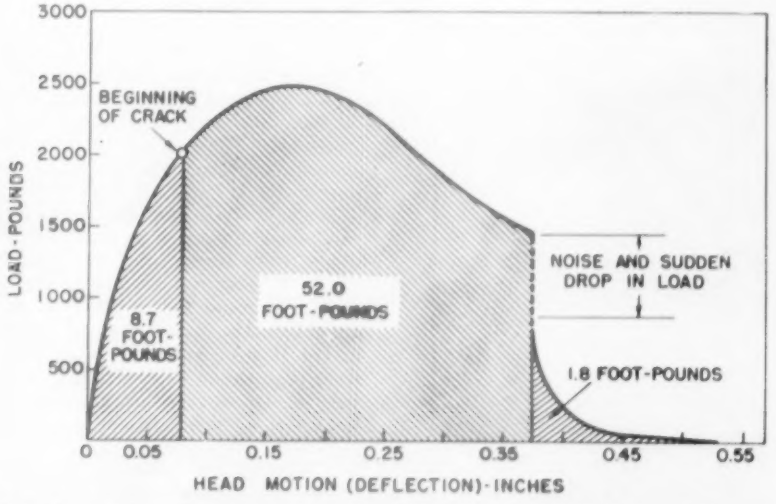

Fig. 13 Room-temperature slow-bend test of standard V-notch Charpy specimen cut in rolling direction from 4-in. hot-rolled mild steel plate. Notch in transverse direction of plate

Table 3—Ductility of Mild Steel in Wide,* Unnotched Bend Tests (Percent Tangential Strain)

	Lot I	Lot I
Ground surface		
Rolling direction	100	68
	120	58
		84
		72
Transverse direction	56	55
	69	56
		66
		68
Normal direction	14	15
	16	24
		10
		9
Polished surface		
Rolling direction		48
		52
Transverse direction		48
		35
Normal direction		14
		15

* Lot I specimens were $1^1/_2$ in. wide by $^1/_4$ in. deep ($S_2/S_1 = 0.48$).[17] Lot II specimens were 2 in. wide by $^3/_{16}$ in. deep ($S_2/S_1 = 0.50$).

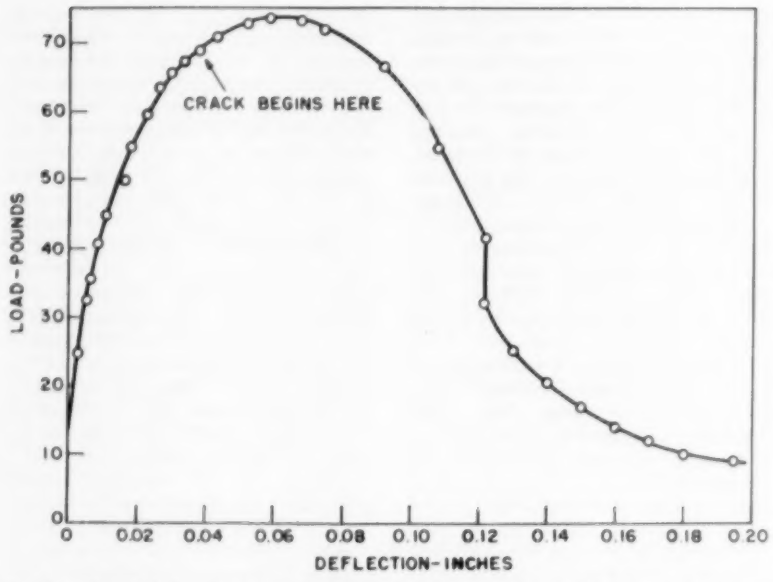

Fig. 16 Load-deflection curve for V-notch Charpy specimen 0.08 in. sq, slow bent at room temperature on $^3/_8$-in. span. Mild steel

the crack propagated gradually over only a small fraction of the depth of the specimen, in some cases not even spreading all the way to the side faces, Fig. 12; and then the specimen suddenly broke in two. In contrast, the small specimen tore open gradually to mid-depth, with very large energy absorbed. In fact, as the crack propagated, the bending load first increased from 2000 to 2500 lb before it decreased again. This behavior is illustrated in Fig. 13, which shows a load-deflection curve obtained with a Baldwin-Southwark stress-strain recorder. Later in the test, there was a sudden drop in load from about 1500 to 800 lb, accompanied by a noise, with gradual tearing then prevailing until complete separation occurred. Figure 14 shows the fracture surfaces, from which the zone of gradual tearing from the notch bottom to mid-depth is very evident. The fracture surface opposite the notch also appears somewhat different from the cleavage appearance just below mid-depth; this region presumably corresponds to the tail on the end of the curve of Fig. 13. The gradual tearing to mid-depth is accompanied by enormous amounts of transverse contraction at the notch bottom (Fig. 14) and absorbed energy (Fig. 13) in comparison to that experienced up to the initiation of the crack. There were 10 mils of contraction up to crack initiation, and 80 additional mils contraction during crack propagation. Thus, the character of the crack propagation was spectacularly different for the large and small specimens. This size effect will be examined in greater detail by means of tests on Lot II material.

The tests on size effect in Lot II steel covered a size range of 25, from 0.08 in. square to 2 in. square. The results (Table 2) confirmed the previous conclusion that size has no effect on the ductility. Also, as the size was varied in Lot II steel, variations in mode of crack propagation were exhibited which were similar to those noted earlier in Lot I steel. The 2-in. bar tore open only about $^1/_{32}$ in., or 2% of the depth, before sudden crack propagation occurred; the 0.4-in. bar tore open about $^3/_{32}$ in., or 30% of the depth; and the 0.08-in. specimen tore open to 50% of the depth before exhibiting any sudden crack propagation, and then only by a very small amount. The fracture surface of the largest specimen was entirely cleavage except for a very narrow band of fibrous fracture around the edges. The fracture surface of the smallest specimen was entirely fibrous except for a few tiny cleavage areas near mid-depth.

The different behaviors of specimens of different sizes is also reflected in their load deflection curves. In the largest specimens, there was comparatively little deflection between the time the first crack appeared and when sudden rupture occurred. The load was still rising prior to sudden rupture, but at this point the load dropped practically to zero, Fig. 15. In the smallest specimens, there was a great deal of deflection while the crack was tearing open gradually, much of it under diminishing load. When sudden rupture occurred there was only a minor drop in load, Fig. 16. These characteristic variations in the shape of the load-deflection curve with size were also noted by Docherty,[5] whose results show very clearly how sudden rupture is sooner and more complete in a larger specimen. However, the initiation of the gradual tearing, which precedes the sudden rupture, was much more obscure in Docherty's results. According to Sachs[10] "...the ductility...decreases with increasing section size"; but the graph (Fig. 2 of Sachs' paper) in support of this statement depicts what appears to be the

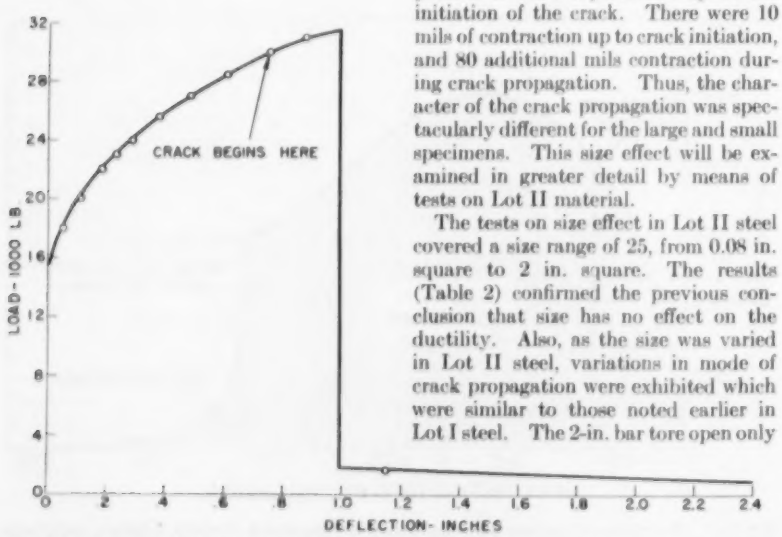

Fig. 15 Load-deflection curve for V-notch Charpy specimen 2 in. sq, slow bent on 11-in. span at room temperature. Mild steel

bend angle up to sudden rupture rather than up to the beginning of tearing. Docherty himself, on the other hand, implies that the load-deflection curves are similar up to Point Y, where "tearing begins." If such were the fact, one would in turn conclude that the ductility is independent of specimen size. In any case, it is clear from the dimple at the notch bottom in the photograph of Docherty's Fig. 6 that considerable strain occurred prior to fracture even in the largest specimen. This dimple appears similar to the one developed in an aluminum specimen at a rather large notch strain.[6]

The confusion regarding size effect in mild steel stems mostly from ambiguous nomenclature. The term "brittle" is often used indiscriminately, sometimes referring to a very small strain preceding the first crack, and sometimes referring to sudden crack propagation, with resulting cleavage appearance of the fracture surface. These two usages of the word "brittle" are in no way synonymous. Figure 5, for example, shows a 2-in. notched-bend specimen which is very ductile, but which exhibits very brittle crack propagation. There was a local strain of at least 50% at the notch bottom before the first cracks appeared.* This large local plastic flow resulted in a pronounced dimple in the side faces at the notch bottom, Fig. 5 and the general curvature shows that considerable plastic strain occurred even at points remote from the notch bottom. After the first slight crack appeared, however, the fracture was a sudden, cleavage fracture propagating the full depth of the specimen, Fig. 5. Thus, it is entirely possible to have ductile behavior followed by brittle crack propagation in the same specimen.

It is particularly important to distinguish between "brittleness" (in the sense of little flow before crack initiation) and brittle crack propagation whenever the quantity being measured depends on both of these phenomena. Such a quantity is the energy absorbed during the test, as in an impact test or slow-bend test. Kahn and Imbembo[11] have shown that the energy absorbed in a navy tear test should be regarded as the sum of the energy for crack initiation and the energy for crack propagation. When the test results are viewed in this way it becomes clear that the transition temperature is associated with a change in the mode of crack propagation, rather than a change from ductile to brittle behavior, because the energy for crack initiation is essentially independent of temperature, while the energy associated with the propagation of the crack falls abruptly to zero as the temperature is lowered below the transition temperature. The energy for crack initiation may be only a small fraction of the total (Figs. 13 and 16), as discussed also by Van der Veen[12] and Tipper.[13]

A second quantity which depends on both ductility and mode of crack propagation is the change of dimensions after complete separation, such as the contraction in width at the base of the notch of a notch-bend specimen or the reduction of area (measured after fracture) of a notch-tensile specimen. It has been noted earlier that 90% of the contraction in width of the specimen of Fig 14 was associated with the propagation of the crack. This same phenomenon probably also explains the effect of size on reduction of area observed by Brown, Lubahn and Ebert[14] in notch-tensile tests of mild steel, as follows. It is known[3,15] that considerable contraction of the notch diameter occurs during the gradual tearing that commences at the notch bottom (McAdam's "rim effect"). It is also known that gradual tearing goes over to sudden rupture earlier in a larger specimen, as discussed above. Consequently it is easy to imagine that the reduction of area in notch-tensile tests up to crack initiation is independent of size, while the reduction of area measured after complete separation is much smaller in the larger specimens, because of the earlier termination of the gradual tearing.

A third quantity which depends on both ductility and mode of crack propagation, though to a smaller degree than the others, is the load-carrying capacity. Figure 13 shows that the bending load may rise as much as 25% while gradual tearing is going on. This increase is due to the fact that the strain hardening associated with the large plastic deformation ahead of the advancing crack more than compensates for the encroachment of the crack on the cross section. Docherty's results show that the size-corrected bending strength is greater for the smaller specimen because of the rising load during gradual tearing. It seems reasonable to suppose that the same phenomenon also accounts for the effect of size on notch strength observed by Brown, Lubahn and Ebert.[14]

One may ask this question regarding the size effect in notch bend tests: which dimension (length, width or depth) is the one that governs the size effect? In order to throw some light on this question two specimens were tested in addition to the large and small square ones already described. One of these had the 0.4-in. width of the standard-size notch bar and the 4-in. depth* of the large 4-in. square bar, while the other specimen had the 0.4-in. depth of the standard bar and the 4-in. width of the large square bar. In both specimens the notch depth and root radius were in the same proportion to beam depth as in a standard V-notch Charpy-impact specimen.

The deep narrow bar exhibited gradual tearing to mid-depth, and then sudden rutpure, Fig. 17. Examination of the fracture surfaces, Fig. 18, revealed that in the initial stages of the gradual tearing there are 45-deg shear lips on both sides which nearly meet in the middle, with a small patch of cleavage between them on a normal plane. Then the tearing followed a shear plane to mid-depth with occasional small cleavage patches at mid-width. The final sudden rupture was by cleavage on a normal plane. Apparently the specimen was on the verge of cleavage failure several times, including once very early, but the narrowness of the specimen

* To prevent buckling of this deep narrow specimen, a short length was welded between larger end pieces, Fig. 17.

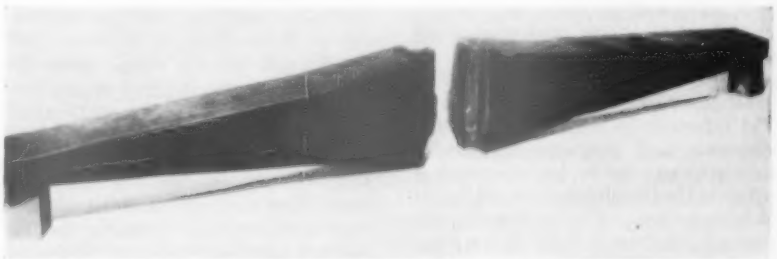

Fig. 17 Deep, narrow, notch-bend specimen

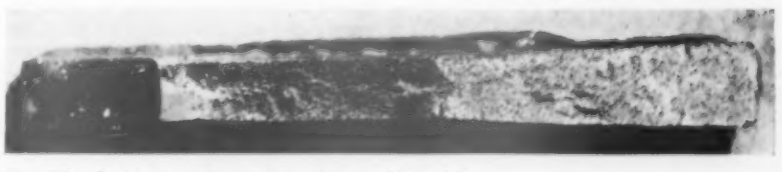

Fig. 18 Fracture surface of specimen of Fig. 17

* Microsection of a smaller specimen containing strains of the same magnitude is shown in Fig. 7a.

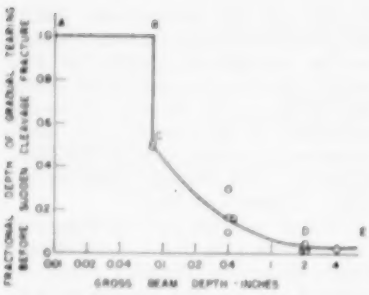

Fig. 19 Fractional depth of shear lip at root of notch, as a function of size of specimen

allowed the side shear lips to so nearly meet in the middle that conditions for cleavage were not very severe.

The lesser severity of crack propagation in the deep, narrow bar than in the large square one also may have been due partly to a notch sharpness effect. Both specimens had the same notch root radius, but the narrower specimen should have had less transverse restraint, and therefore less biaxiality, because of the proximity of the side faces (where biaxiality equals zero) relative to the root radius (see also Reference 6).

The wide, shallow bar exhibited intermittent sudden crack advances rather than one sudden crack advance as in the standard bar. Examination of the fracture surface revealed a few narrow, faint bands of fibrous fracture, thus indicating that gradual tearing was interspersed between the sudden crack advances. The number and severity of the intermittent, sudden crack advances depended on the bending span. For a $4^1/_2$-in. span, there were a great many sudden crack advances; for a rather fast rate of head motion, these sudden crack advances came in such rapid succession and in such large numbers that the specimen made a crackling sound as it tore open. For a 27-in. span, by contrast, there were only three sudden crack advances, the first and third being accompanied by a much louder noise than those observed for the short-span test. The differences in behavior between the long-span and short-span 4-in.-wide specimens was also evident from examination of the fracture surfaces after complete separation. The short-span specimen exhibited much more fibrous fracture interspersed with the cleavage than did the long-span specimen. Also there was much more of an appearance of directionality in the fracture surface of the short-span specimen, indicating the presence of many narrow fibrous bands, as noted earlier. These bands could not be singled out with either the microscope or the naked eye, however, nor could the two fibrous bands which should have been present between the three cleavage zones in the long-span specimen be clearly recognized.

In the wide specimens tested on either a short or a long span, the depth of fibrous tearing was much smaller than in standard bars—almost too small to detect. Thus, increasing the width of a standard bar to 4 in. causes the cleavage to begin earlier, but to stop sooner than in a standard bar. Increasing the length* of a wide bar causes the cleavage to go farther, but still not as far as in a standard bar tested on a short span.

To summarize: A specimen with a 4-in. width and 4-in. depth tested on a long span has a much more severe crack propagation behavior than a 0.4-in.-wide 0.4-in.-deep specimen tested on a short span; but neither a 4-in. depth and long span, combined with the narrow width of 0.4 in., nor a 4-in. width and long span, combined with the shallow depth of 0.4 in., was as severe a combination of conditions as both large width and large depth. Thus, *both* large width and large depth are necessary in order to cause the full size effect, and apparently also a longer length (span) is necessary to obtain the full effect when a wider width is used. From these observations it is evident that several factors must all be present in combination to cause the early and complete sudden rupture observed in large, square notched bars. One factor is a sufficient width that the side shear lips do not meet at mid-width. Probably another factor is a sharp enough notch compared to the width to give a high degree of transverse restraint (plane strain). The amount of stored energy certainly must exceed a certain minimum, in order to supply the surface energy of the new cleavage surfaces; and the results show that when the distance of sudden crack advance is small, this distance can be increased by lengthening the bending span. Many tests would be required to clarify the factors required to cause the size effect: various combinations of large or small depth, large or small width, large or small length (or stored energy), large or small root radius and possibly others.

Fig. 20 Schematic diagram showing the manner in which tearing occurs at the notch bottom; usually diagonal tearing from opposite sides occurs alternately along the length of the notch, but occasionally the two tears occur opposite each other, and a triangular piece breaks out

That one such factor may be the root radius can be discerned from observations on the nature of the shear lip along the notch bottom. As discussed earlier, the depth to which fibrous tearing extends away from the notch bottom is a smaller and smaller fraction of the depth as geometrically similar specimens are increased in size from 0.08 to 2 in. square. However, in going from 2- to 4-in. bars, an *increase* in the depth of fibrous tearing (shear lip) is observed. This is an absolute increase in shear lip width which appears to be approximately double for double specimen size. Thus, the shear lip is a constant percentage of the depth, and therefore also a constant percentage of the notch radius for geometrically similar specimens.

The fractional depth of the shear lip in notched square-bend bars can now be expressed tentatively as a function of size, Fig. 19. For small sizes, fracturing is by gradual tearing over the full depth (Region A B). At B, the size becomes large enough to permit slight cleavage at mid-depth, and the fractional depth of the shear lip is 0.5. This size is about 0.08 in the steel tested. With further increase in size the fractional depth of the shear lip decreases to about 0.02 in a transition Zone CD, and then remains constant (Zone DE). For the steel tested, the 0.4-in. size is in the Zone CD, and the 2- and 4-in. sizes are in Zone DE.

A closer scrutiny of the shear lip on specimens in the size range DE of Fig. 19 reveals that the fibrous tearing begins high on the root radius and proceeds diagonally (Fig. 7*a*) toward a point below the notch bottom, as shown schematically in section in Fig. 20. This

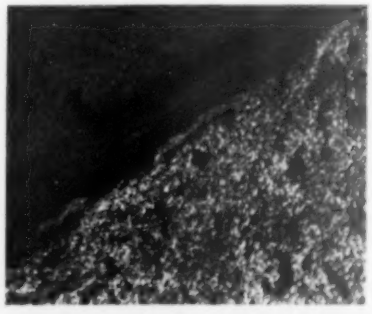

Fig. 21 Fracture surface at notch bottom of 4-in. notch-bend specimen. Dark area above is side wall of notch, which shows small cracks on root radius just beyond edge of fracture surface

* Increasing the length of a standard bar had no effect. This result is not surprising, since cleavage proceeded nearly all the way through anyhow in a standard bar tested on a short span.

diagonal tearing is shown in its early stages in Reference 1. At a given point along the length of the notch, the tearing is predominantly from one side only, Fig. 7*a*, though occasionally balanced tearing occurs from both sides and a small triangular piece breaks out. In general there are alternate diagonal tears from opposite sides, which appear on a broken half of the specimen as bevels when viewed from above and projecting wedges when viewed brom below, Fig. 21. In the larger sizes of specimens, the cleavage appears to start from the point (*A* in Fig. 20) where the tears reach a common plane (the plane of symmetry). Such a behavior would account for the observation that the shear lip width is proportional to the radius, since the fracture pattern is similar in geometrically similar specimens.

If the above picture is correct, the crack propagation behavior in large specimens could be made more severe by reducing the notch radius, presumably eliminating the shear lip entirely by making the notch sufficiently sharp. This suspicion was borne out by a test on a 2-in. square bar with a 0.4-in. deep, 45-deg notch machined as shape as possible (about 0.001 in. root radius). Cleavage began immediately at the notch bottom, without any evidence of prior shear even in a microsection. However, the cleavage fracture did not proceed very far; and cleavage was intermittent throughout the test, with considerable plastic bending between. This behavior is in sharp contrast to that observed in the same sized bar with a 0.050 in. root radius, where sudden fracture, once started, proceeded practically all the way through the specimen. The considerable intermittent bending in the sharply notched specimen is evident in Fig. 4 from the failure of the two halves to fit together again, as contrasted with the specimen with the radiused notch, Fig. 5.

Thus, the sharper notch induced earlier cleavage failure, as expected; but somehow the conditions for continued crack propagation by cleavage were then no longer present. The reason for this is not clear, but perhaps the stress distribution around the sharper notch is such that there is not enough stored energy in the right locations to continue to feed the propagation of the cleavage fracture. Certainly the highly stressed region is smaller in the sharply notched specimen, both from the viewpoint of restraint in the direction of the depth[16] and because of the distribution of the strain hardening. Simply increasing the total stored energy (by increasing the length, for example) apparently would not cause complete cleavage failure, since the total energy was already nearly the same in the sharply notched and mildly notched bars.

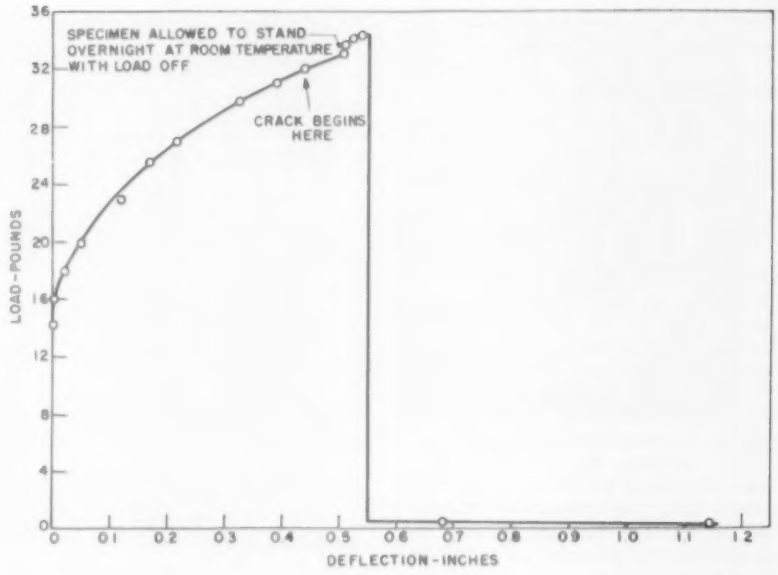

Fig. 22 Load-deflection curve for V-notch Charpy specimen 2 in. sq, slow bent on 11-in. span at room temperature. Mild steel

Effects of Cold Work and Strain Aging

It is commonly believed that "ductility" is a definite quantity, which can be associated with a particular number. This concept stems from the use of reduction of area measurements made after separation of a tensile test specimen, where the final diameter is rather easily measured. In the case of bending, however, the whole process of crack initiation is so gradual that a "ductility" value, or strain at crack initiation, can be assigned only with some arbitrariness. This fact has been discussed by Low[2] who observed highly polished surfaces at high magnification after straining under rather brittle conditions. He showed that the "strain at the first crack" depends on how diligently one searches for that first crack. Considerable uncertainty exists also in the observation of crack initiation in machined surfaces deformed at room temperature, where a lower magnification of 20–30 × is required to minimize the confusing effects of orange peel.* Under these conditions, the ductility was taken as the strain at which one observed the first crack large enough and deep enough to be certain that it really was a crack, rather than something of debatable nature, which in many cases could not even be located again after some additional bending. All the ductility values quoted above were measured according to this arbitrary criterion.

Of course, the above criterion of ductility results in values which depend considerably on how careful and critical the observer is, and which are therefore somewhat vague. In an attempt to develop a more specific criterion of ductility, observations were carried out on several notch-bend specimens with the notch bottom lapped with a rotating wire. This procedure did not remove the previous uncertainties; it only served to shift the uncertain range to lower values of ductility. Where a suspicion of a crack at 50% strain developed into an obvious crack at 70% strain in a machined surface, a suspicion of a crack at 10% strain developed into an obvious crack at 20% strain for a lapped surface. A much smaller crack could be detected in a lapped surface than in a machined surface, and by the time it had grown to the size necessary for easy detection if it had been in a machined surface, the apparent strain in the lapped surface had increased to 60 or 80%. In testing unnotched-bend specimens a similar observation was made (Table 3) but the effect was not as pronounced.

The apparently lower ductility values for lapping than for machining seemed surprising, because one would expect the more heavily worked, machined surface layer to be the more brittle. The reason for this unexpected behavior became clear when a test was made on a notch-bend specimen with a machined surface that had become discolored during prolonged storage. At about 40% strain, this specimen developed shiny streaks in the otherwise tan surface, but did not show "cracks" until about 70% strain. These streaks were lengthwise of the notch and were tapered to points at the ends as are cracks, but they did not seem to have any depth at all. Ap-

* Surface roughening during straining because of anisotropic deformation of the differently oriented grains.

parently the thin, hard skin from the machining had split open, revealing broad, shallow cracks. In nonoxidized samples, these cracks were too shallow to give any indication that a new surface was forming. They merely contributed to the surface roughness already prevailing because of the orange peel, and made it harder to detect the first deep, narrow cracks when they did appear.

In most of the tests described above, the procedure involved frequent unloading, with inspection for cracks and measurement of the bend angle. In a few cases the test was continued the next day, after having had some strain and/or tearing on the preceding day. On the second day, a distinctly larger load was always required in order to cause continued bending, Fig. 22. This effect was attributed to strain aging. The strain aging also affected the character of the fracture; cleavage fracture appeared to set in somewhat earlier if there had been strain aging.

Acknowledgment

The author is indebted to H. L. Couch for assistance in making the tests.

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SPRAYING WELDING SCARVES WITH ALUMINUM

BY A. LEROY, H. GRANJON AND M. EVRARD

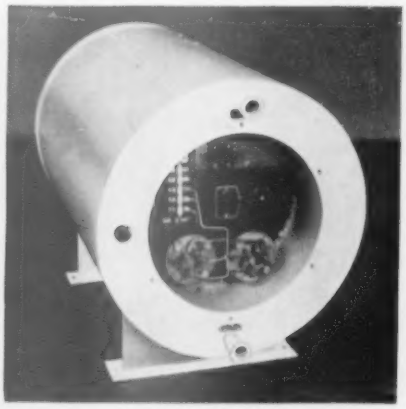
(Abstract of "Sur un procédé de calmage du bain de fusion dans le soudage des aciers," published in *Soudage et Techniques Connexes*, **9**, 127–130 (1955). The authors are associated with the French Institute of Welding.) Abstracted by Dr. G. E. Claussen.

In the welding of rimmed steel by the inert arc process it has been difficult to avoid porosity. The carbon and oxygen in the steel react during welding to form CO, which is trapped in the steel during freezing. In welding rimmed steel with covered electrodes or by the submerged arc process, the oxygen combines with deoxidizers and no CO porosity is observed.

The porosity difficulty was particularly troublesome with pickled sheets 0.08 in. thick containing 0.08 C, 0.24 Mn, 0.036 S, 0.012 P. Porosity was prevented by applying to the edges of the sheet a paste containing 25% FeSi (45% Si) and 75% TiO_2. The amount of paste was difficult to control, excessive paste causing cracks.

To accomplish a similar effect aluminum was sprayed on the edges to be welded. The metal spray gun was used to roughen the surfaces to be welded. About four particles of sprayed aluminum per square millimeter provide the best results. There is no porosity and the bend specimens are satisfactory. Aluminum spraying can be replaced by painting or electrolysis, provided no other elements are introduced that might cause porosity.

Aluminum spraying is not confined to argon arc welding of sheets. Rimmed Bessemer steel $^3/_8$ in. thick with mill scale could not be submerged arc welded at over 520 amp and 20 ipm without porosity. Spraying the scarves with aluminum permitted an increase to 620 amp and 32 ipm. Rusty scarves caused porosity unless the rust was dehydrated by a torch. A French patent application (No. 676, 390 of Sept. 18, 1954) has been filed for the aluminum spray process of deoxidizing weld metal.



ABOVE: A completed Hubbell booster water heater.

LEFT: Welding the head on a 10-gallon Everdur booster heater tank using Anaconda ⅛" Everdur-1010 Rod. All spuds, flanges and fittings are Everdur.

Everdur tanks...welded with Everdur-1010 rod make long-life booster water heaters

Water at 180F may be highly corrosive. Yet 180-degree rinse water is required by many sanitary codes for sterilization in commercial dishwashing machines.

The Electric Water Heater Co. of Stratford, Conn., makers of Hubbell water heaters, and one of the pioneers in the electric water heater business, builds 10-gallon and 20-gallon models for just this service. Experts in the design and fabrication of water heating equipment, Electric Water Heater Company is also a pioneer in the use of Everdur* for its tanks.

The tinned Everdur tanks for booster heaters are welded by the carbon-arc method, using Everdur-1010 Welding Rod. In this tough service in restaurants, hotels, schools and institutions, the tanks have performed dependably and are considered to have a long life expectancy.

AnacondA Welding Rods for many types of welding are available from distributors throughout the United States and Canada. See your distributor for help in selecting the exact rod to help you speed assembly and cut production costs. Or write for Publication B-13. Address The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

*Reg. U. S. Pat. Off. 54135

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NAME OF WELDING ROD	APPROX. MELTING POINT, DEGREES Cent.	Fahr.	USUAL APPLICATIONS
*ANACONDA COPPER-372 (Patent No. 2,220,464)	1075	1967	Inert-gas arc and oxyacetylene welding of copper.
TOBIN BRONZE-481	885	1625	Oxyacetylene braze welding of steel, cast iron, and copper alloys.
ANACONDA-997 (Low-Fuming) BRONZE	870	1598	A low-fuming manganese bronze for use where the highest weld metal properties are required. Oxyacetylene braze welding of steel, cast iron, and copper alloys, and for bearing surfaces.
NICKEL SILVER-828	930	1706	Oxyacetylene braze welding of cast iron and steel for strong, color-matching welds and bearing surfaces.
CUPRO NICKEL-826 (Patent No. 2,012,450)	1225	2237	Oxyacetylene welding of Cupro Nickel and surfacing of steel.
*EVERDUR-1010	1019	1866	Inert-gas arc, carbon-arc and oxyacetylene welding of Everdur, copper and copper alloys. Also for welding to, and for surfacing steel.
*PHOSPHOR BRONZE-351	1050	1922	Inert-gas and carbon-arc welding of phosphor bronze and copper, and for surfacing steel.
*PHOSPHOR BRONZE-354	1000	1832	Inert-gas and carbon-arc surfacing of steel, and for welding phosphor bronze.
**AMBRALOY-928	1040	1904	Inert-gas consumable-electrode welding of aluminum bronze and for surfacing steel.

*These alloys are also used in the inert-gas consumable-electrode process. Spooled rods are marketed by the manufacturers of the welding equipment.

**Supplied only on spools by the manufacturers of the welding equipment.

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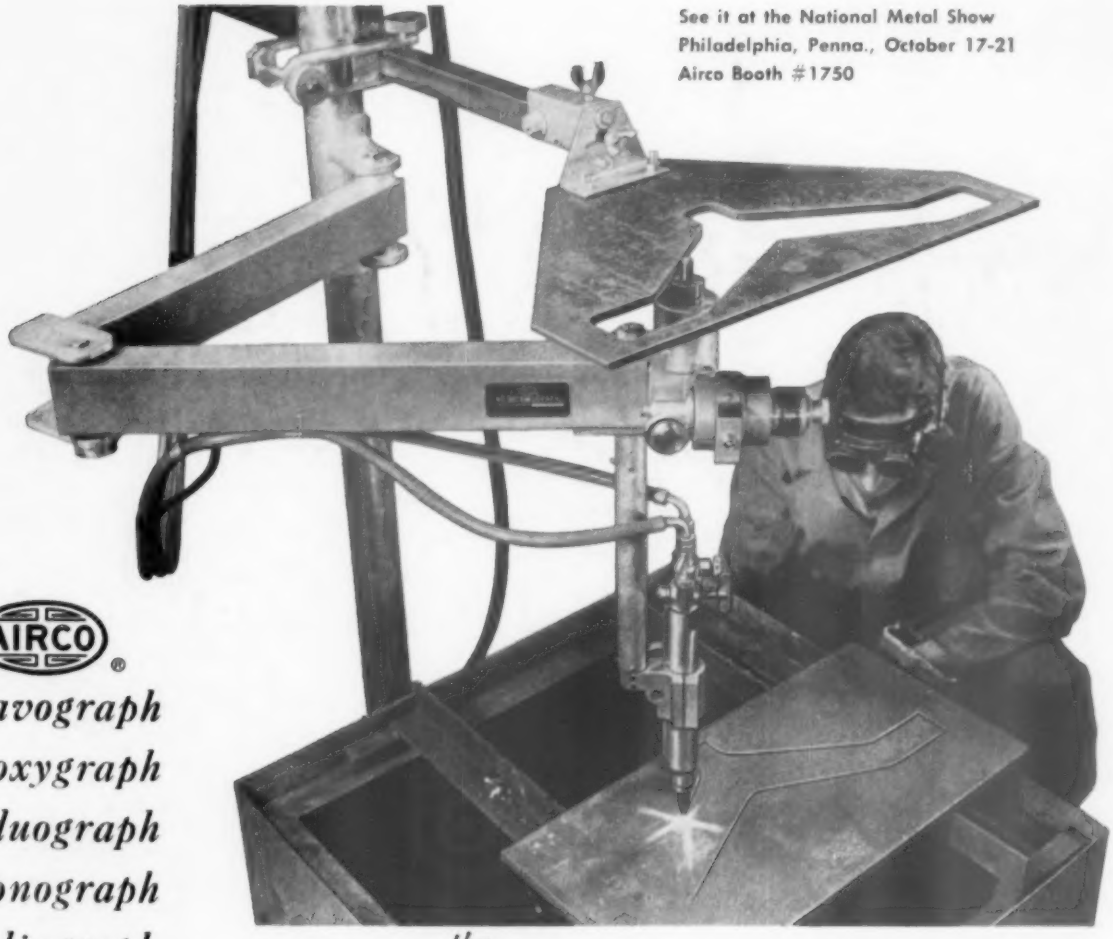

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